This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Water-Supply and Irrigation Paper No. 182 Series O, Underground Waters, 62

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

FLOWING WELLS AND MUNICIPAL WATER SUPPLIES

IN THE

SOUTHERN PORTION

OF THE

SOUTHERN PENINSULA OF MICHIGAN

BY

FRANK LEVERETT AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

BRANNER
GEOLOGICAL LIBRARY

STANFORD UNIVERSITY LIBRARIES

Water-Supply and Irrigation Paper No. 182 Series O, Underground Waters, 62

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

FLOWING WELLS AND MUNICIPAL WATER SUPPLIES

IN THE

SOUTHERN PORTION

OF THE

SOUTHERN PENINSULA OF MICHIGAN

BY

FRANK LEVERETT AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

91

659142

CONTENTS.

	Page.
Introduction, by Frank Leverett	1
Scope of report	1
Geographic features	4
Water-bearing formations	7
Structure of drift	8
Character of drainage	9
Rainfall	10
Ground-water table	11
Wells and appliances	12
Quality of water	14
Subterranean water temperature	14
Legislation	21
Flowing wells	22
Municipal and institutional water supplies	23
Monroe County, by Frank Leverett	25
Topography	25
Flowing wells	25
General statement	25
Eastern artesian belt	26
Middle artesian belt	27
Milan-Cone district	27
Well data by townships	29
Lower Huron River region, by Myron L. Fuller	33
Introduction	33
General statement	33
Geology	34
Surface materials	34
Rocks	35
Water supplies	35
Willow-Exeter region	36
Carleton region	38
Swan Creek region	38
Huron River region	40
Rockwood region	41
Detroit River region	43
Grosse Isle	43
Decline of water supply	44
Present conditions	44
Causes of decline	45
Conclusions	47
Wayne County, by William Hittell Sherzer	48
General statement	48
Rainfall	49
Surface waters	50
Reservoirs	50
Lakes	51
Streams	52
Detroit River	52
Smaller streams	58

Wayne County, by William Hittell Sherzer—Continued. Page.
Ground waters 60
Lacustrine and river deposits 60
Formation of deposits 60
Water supply 61
Glacial deposits 64
Formation of deposits 64
Water supply 65
Bed rock 73
Geologic formations 73
Water supply 73
Lenawee County, by Frank Leverett 78
General statement 78
Waterworks 79
Adrian 79
State Industrial Home for Girls 80
Hudson 80
Tecumseh 80
Miscellaneous village supplies 80
Flowing wells 82
York district 82
Holloway district 87
Ogden Township 89
Sand Creek 91
Morenci 91
Medina 94
Rollin Township 94
Hudson Township 95
Tipton district 95
Wolf Creek district 97
Hillsdale County, by Frank Leverett 98
Topography 98
Waterworks 99
Hillsdale 99
Jonesville 99
Reading 99
Miscellaneous village supplies 100
Flowing wells 100
Ransom Township 100
Jerome 101
Moscow Township 102
Wheatland Township 102
Allen Township 102
Camden 103
Cambria Township 103
Branch County, by Frank Leverett 104
General statement 104
Waterworks 104
Coldwater 104
Quincy 104
Union City 104
Miscellaneous village supplies 105
St. Joseph County, by Frank Leverett 105
General statement 105
Flowing wells 105
Klingers Lake 105

Joseph County, by Frank Leverett—Continued. Page.
Waterworks 106
Three Rivers 106
Sturgis 107
Centerville 107
Constantine 107
ss County, by Frank Leverett 108
Topography 108
Miscellaneous village supplies 108
Flowing wells 108
Glenwood district 108
Long Lake 109
West of Dowagiac 109
Fish Lake 109
Waterworks 109
Dowagiac 109
Cassopolis 110
Marcellus 110
lerrien County, by Frank Leverett 110
Topography 110
Waterworks 111
Niles 111
Buchanan 112
Three Oaks 112
Benton Harbor 112
St. Joseph 112
Eau Claire 113
Miscellaneous village supplies 113
Flowing wells 113
Galien district 113
Weesaw Township 114
New Buffalo district 114
Pipestone district 114
Bainbridge district 117
Pawpaw Lake 118
'an Buren County, by Frank Leverett 119
Topography 119
Waterworks 120
Bangor 120
Decatur 120
Hartford 120
Lawrence 120
Pawpaw 120
South Haven 120
Miscellaneous village supplies 121
Flowing wells 121
Hartford Township 121
Pawpaw Township 122
Antwerp Township 123
Waverly Township 123
Arlington Township 124
Bangor Township 125
Geneva Township 125
Columbia Township 125
Bloomingdale 126
Pine Grove Township 126

P

Kalamazoo County, by Frank Leverett
Topography
Waterworks
Kalamazoo
Vicksburg
Fulton and Oshtemo
Miscellaneous village supplies
Flowing wells
Calhoun County, by Frank Leverett
Topography
Waterworks
Albion
Battle Creek
Marshall
Miscellaneous village supplies
Flowing wells
Jackson County, by Frank Leverett
Topography
Waterworks
Jackson
Miscellaneous village supplies
Flowing wells
Jackson
Norvell-Brooklyn-Clarks Lake district
Washtenaw County, by Frank Leverett
General statement
Ann Arbor
General supplies
Flowing wells
Waterworks at Ann Arbor
Waterworks
Ypsilanti
Chelsea
Village supplies
Dexter
Saline
Milan
Flowing wells
Pittsfield Junction district
Sharon Township
Manchester district
Allegan County, by Frank Leverett
Topography
Waterworks
Allegan
Otsego and Plainwell
Miscellaneous village supplies
Flowing wells
Watson-Otsego district
Western part of county
Graatschap area, by Isaiah Bowman
Wayland area, by Isaiah Bowman
Barry County, by Frank Leverett
Topography

rry County, by Frank Leverett—Continued. Page.
Waterworks, by Isaiah Bowman 161
Hastings 161
Nashville 162
Miscellaneous village supplies 163
Flowing wells, by Isaiah Bowman 163
ton and Ingham counties, by Isaiah Bowman 164
General statement, by Frank Leverett 164
Waterworks 165
Eaton Rapids 165
Charlotte 166
Mason 168
Flowing wells 168
Charlotte district 168
Bismarck-Roxana district 169
Leslie district 169
nsing and vicinity, by A. C. Lane 170
Geology 170
Physical characteristics 171
Character of the drift 171
Depth to rock 171
Quality of water 172
Waterworks 173
Flowing wells 174
Flows from drift 174
Flows from rock 174
Miscellaneous flows 175
Oakland County, by Frank Leverett 176
General statement 176
Waterworks 177
Pontiac 177
State asylum for the insane 177
Milford 178
Oxford, by Charles A. Davis 178
Holly, by Charles A. Davis 180
Birmingham, by Jon A. Udden 182
Rochester, by Jon A. Udden 182
Miscellaneous village supplies 183
Flowing wells 184
Ortonville district, by Charles A. Davis 184
Groveland Township, by Charles A. Davis 187
Big Meadows area, by Charles A. Davis 188
Troy district, by Frank Leverett and Jon A. Udden 188
Avon Township, by Jon A. Udden 195
Macomb County, by Frank Leverett 196
General statement 196
Waterworks 197
Mount Clemens 197
New Baltimore 198
Richmond and Lenox 198
Armada 199
Romeo 199
Miscellaneous village supplies 200

Macomb County, by Frank Leverett—Continued. P.
Flowing wells
Bruce Township
Washington-Ray district
Utica area
Lake St. Clair shore
St. Clair County, by Frank Leverett
General statement
Waterworks
Capac
Yale
Miscellaneous village supplies
Flowing wells
East Greenwood district
Clyde Township
Smiths Creek
Columbus Township
Lapeer County, by Frank Leverett
General statement
Waterworks
Imlay City, by Charles A. Davis
Lapeer, by Charles A. Davis
Michigan Home for Feeble-Minded
Almont
Columbiaville
Miscellaneous village supplies
Flowing wells
Attica Township
Lum
Burnside district
North Branch district
Clifford
Silverwood district
Columbiaville districts
Northern Clinton County, by Isaiah Bowman
General statement
Flowing wells
Eureka district
Maple Rapids district
St. Johns district
Shepardsville district
Elsie and vicinity, by Charles A. Davis
Waterworks
Ovid
St. Johns
Fowler
Eagle
Ionia County, by Isaiah Bowman
General statement
Flowing wells and springs
Belding
Clarksville district
Hubbardston district
Ionia district
Shiloh area

Name and location.	Class.	Pump.	Depth in feet.	Head in feet.	Temperature (°F.). May.	June.	July.	Aug.	Sept.	Oct.	Nov	Dec.	Jan.	Feb	Mar.	Apr.	Annual average
State street spring; base of gravel, piped several rods.	Issuing		0	0	51.2	53	54.5	55.5	54.8	53.5	50.3	47	45	42.5	42.5	46	49.8
White estate spring; base of bluff, piped several rods.	do		0	0	50.8	51	51.3	51.5	51	50.3	49.8	49	49	.....	49	49.7	50.2
Rash Spring; bed of ravine	Boiling		0	0	51	51	51	51	51	50.8	50.7	51	51	51	51	51	50.95
Buehler well; in ravine	Dug	Wooden	12	−5 / −10	45.5	47.5	49	50	51.2	52	51	49	45.8	45	44.3	44	47.86
Rash well; on bluff, 34 feet above Rash Spring.	do	Iron	23	−22	45	47	48	48.9	49.9	51	50.5	48.8	46	46	45.5	45	47.6
Schaeberle well; on gravel terrace capped by clay.	do	Wooden	18	−9 / −17	46.5	48.5	49.5	51.6	52.4	53	52	49	47.5	45.5	44	45.8	48.77
Levy well; on terrace sunk through gravel into till.	do	Iron	80	−40	48.3	49	49.8	50.5	51	51	50.5	50.5	50.3	46	48.3	48.3	49.5
Observatory well; on moraine, with plank cover.	do	None	15	−11 / −14	45	46.5	48	51	52	52.5	50	46.9	41	37	43	41.6	46.2
Carroll well; on moraine near observatory, no cover, water drawn with windlass.	do	Windlass	24	−20 / −22	46.5	46.5	48	50	49.6	50.3	48.9	45	37	40	41	45	45.57
Niederhummer well; on slope of ravine.	Tubular (2-inch)	Iron	36	−18	50	51	51	51.15	51.15	51.1	51.4	50.3	49.7	50	50.2	49.8	50.57
Duna well; on South State street, in old Huron River channel.	Tubular	do	28	−2	49.8	50.5	50.3	51	51	51.5	50.8	50.5	50.5	50	50	49.5	50.45
Lutz flowing well; in ravine	Tubular (2-inch)	None	112	+3	51.1	51	51	51	51	51	51	50.8	50.8	50.8	50.8	51	50.9
Hutzel flowing well; in ravine	do	do	72	[a]+5	51	51	51	51	51	51	51	51	51	51	51	51	51
Air temperatures at Ann Arbor from daily observations at the observatory.					58.4	66.7	70.8	67.3	62.2	49.4	37.2	22.9	22.7	16.5	37.7	44.8	46.4

[a] Original head +22 feet; loss of head due in part to leakage around pipe.

ILLUSTRATIONS.

		Page.
PLATE I.	Artesian water map of Michigan	5
II.	Geologic map of Michigan	8
III.	*A*, Large spring at United States fish hatchery, Northville, Wayne County, Mich.; *B*, View of the Grosse Isle flowing well	44
IV.	*A*, Type of drilling apparatus used at Ypsilanti and vicinity; *B*, Bonsteel flowing well in 1902, showing old wooden casing and size of stream thirty-two years after completion	140
V.	Map of Troy flowing-well district, Oakland County, showing topographic features in that and bordering districts	188
FIG. 1.	Sketch map showing area covered by report	2
2.	General average of flowing-well temperatures in the Southern Peninsula of Michigan	17
3.	Diagram showing fluctuations in air and well temperatures at Ann Arbor, Mich	20
4.	Map of York and Milan-Cone flowing-well districts	28
5.	Plat of York village, showing distribution of flowing wells	82
6.	Map of Holloway flowing-well district, Lenawee County	87
7.	Flowing wells in Ogden Township, Lenawee County	90
8.	Plat of Morenci, Mich., showing flowing wells	92
9.	Map of southern part of Rollin Township, Lenawee County, showing distribution of flowing wells	94
10.	Flowing wells near Tipton, Lenawee County	95
11.	Flowing wells near Ransom, Hillsdale County	101
12.	Flowing wells (from rock) near Cambria, Hillsdale County	103
13.	Map of Pipestone flowing-well district, Berrien County	115
14.	Flowing wells in Bainbridge and Watervliet townships, Berrien County	118
15.	Map of Waverly flowing-well district, Van Buren County	123
16.	Arlington township flowing wells, Van Buren County	124
17.	Map of part of Bloomingdale, Van Buren County	126
18.	Flowing wells in Sharon Township, Washtenaw County	149
19.	Location of flowing wells in Watson and Otsego townships, Allegan County, in relation to topography and drainage	154
20.	Map of Wayland flowing-well district, Allegan County	156
21.	Plat of Eaton Rapids, showing distribution of flowing wells	165
22.	Conditions at Oxford, Oakland County	179
23.	Conditions at Oxford, Oakland County	180
24.	Diagram across valley at Ortonville, Oakland County	184
25.	Plat of Ortonville, Oakland County, showing location of flowing wells	185
26.	Cross section of Troy flowing-well district, Oakland County	190
27.	Map of Rochester, Oakland County, and vicinity, showing distribution of flowing wells and their topographic relations	195
28.	Map showing relation of flowing wells in Washington and Ray townships, Macomb County, to lake beaches and moraine	201

Page.
IG. 29. Map showing relations of flowing wells in Clyde Township, St. Clair County. 210
30. Flowing wells in Columbus Township, St. Clair County..... 212
31. Flowing wells near North Branch, Lapeer County..... 220
32. Distribution of flowing wells in and near Silverwood, in Lapeer and Tuscola counties..... 222
33. Map showing Eureka flowing-well area in relation to drainage and moraine. 226
34. Flowing wells near St. Johns, Clinton County..... 229
35. Illustration of flow obtained by trenching..... 229
36. Map of Belding flowing-well area..... 236
37. Location of Clarksville flows..... 238
38. Area in and near Ionia in which flows are found..... 241
39. Relation of Cedar Lake flows to topography and drainage..... 247
40. Possible extent of Conklin field over sections where flowing wells occur.... 254
41. Coopersville flowing wells..... 255
42. Map of Bear Creek and Drenthe flowing-well districts..... 258
43. Location of flowing wells at Harrisburg, Ottawa County, and area of probable flows..... 259
44. Plat of Grandville, Kent County, showing distribution of flowing wells.... 273

LEGISLATION.

There are two important legislative acts in reference to Michigan water supplies, copies of which are presented below:

[Act No. 43, Public Acts of 1897; 4484-4486, Compiled Laws, 1897.]

AN ACT to provide for the analysis of water in use by the public in certain cases.

The people of the State of Michigan enact:

SECTION 1. That in any case where any city, village, or township in this State shall be supplied with water for domestic uses by any individual, company, or corporation, city or village, or where there is within such city, village, or township any water in swales, wells, rivers, or other places, which might be the cause of disease or epidemic, a sample of such water may be sent to the University of Michigan for analysis, by the mayor of such city or village, or by any alderman or trustee of such village, or by the supervisor of any such township, upon the resolution of the common council of such city, or board of trustees of such village, or the township board of such township, for that purpose duly passed.

SECTION 2. Upon receipt of such sample the regents of the University of Michigan shall cause a correct analysis of such sample of water to be made, and a correct statement of the properties contained therein, with a further statement whether or not such sample contains any substance deleterious to health, and return such analysis, together with the statement aforesaid to the person so sending the same, free of charge, except the actual cost of materials and animals used in making such analysis and experiment.

SECTION 3. It shall be the duty of the board of regents of the University of Michigan to cause a record to be kept of every sample of water received under and by virtue of this statute, and in no case shall a second analysis be required of the same water within one year except in the case of the breaking out of some disease among the consumers of such waters, and then only upon the certificate of at least two physicians engaged in active practice in that community that in their opinion such disease arises from the use of said water.

Approved March 26, 1897.

[Act 107, session of 1905.]

A BILL to regulate the use of artesian and other wells; to prevent the waste of waters therefrom, and provide a remedy therefor.

The people of the State of Michigan enact:

SECTION 1. Any artesian or flowing well, the water of which is unnecessarily allowed to run to waste in an unreasonable manner to the depletion or lowering of the head or reservoir thereof to the detriment or damage of other wells supplied from the same head or reservoir, shall be deemed a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured that are or may be provided by law for other nuisances or tortious acts.

SECTION 2. Where any well is supplied by a head, reservoir, stratum, or vein, or by percolating waters common to other streams or wells, and the owner thereof or his lessee or licensee puts its waters to a use unreasonable or unnecessary in view of the condition and situation of the land on which it is situated, and through such unreasonable or unnecessary use, lowers or depletes the head, pressure, or supply of water of any spring or well dependent on the same head, vein, or stratum, to the detriment or injury of the owner or any person entitled to the use thereof, the well so unreasonably and unnecessarily used shall be deemed to be a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured, that are or may be provided by law for other nuisances or tortious acts.

SECTION 3. Where any decree is rendered under this act declaring any well a nuisance because of the waste or unreasonable use of its waters and directing the abatement thereof, such decree shall specify in some practicable manner the daily amount or volume of water that may be used or allowed to flow therefrom without violating such decree, and specify

WATER-BEARING FORMATIONS.

The greater part of the Southern Peninsula is covered so deeply with drift that wells do not reach rock. The shaded portions of the map (Pl. I) show the parts of the State where rock is within easy reach of the drill and is drawn upon to some extent for drinking water. In the northern end of the peninsula water is found chiefly in limestone if not in the drift. There is also a limestone district in the southeastern part that serves extensively as a source for drinking water; in some cases in southeastern Lenawee County the wells are driven through shale to reach the limestone. The extensive district running from Hillsdale and Calhoun counties northeastward to Saginaw Bay obtains water chiefly from sandstones of the coal measures and from the Marshall sandstone if water is not found in the drift. There are, however, small limestone districts in this region, the full extent of which has not been worked out. Sandstone is also drawn upon occasionally in western Wayne, southern Washtenaw, and northern Lenawee counties in the deep flowing wells. The Sylvania sandstone of Monroe County is also an important water bearer, yielding a good quality of water. There are small areas around Grand Rapids in Kent and eastern Ottawa counties and around Wayland in northeastern Allegan County where wells are driven to the Marshall sandstone.

Water is found in the glacial formations at various horizons, wherever gravel or sand chances to be present. The clay plains bordering St. Clair River, Lake St. Clair, and Detroit River are deficient in gravel and sand, and are perhaps the poorest water bearers in the peninsula. As a rule water in large quantities is easily obtained in the drift. Even in the regions where wells are driven to rock, as indicated by the shaded portions of Pl. I, there are numerous wells obtaining water from the glacial deposits. The water from rock is usually softer in sandstone areas than that from the overlying drift, and for that reason is preferred and is the cause for going to the rock in many instances.

The sand along the present shore and also along abandoned shores of the Great Lakes is often of sufficient depth to furnish water, though not that of the best quality in many cases. It so happens that these sand deposits occur on parts of the lake plain where the glacial formations are deficient in water-bearing beds and thus become of great importance locally. In general, however, the water from the underlying glacial formations is preferred and is used wherever it can be easily obtained.

The newest formations drawn upon for water are the beds of bog lime bordering the little lakes. Pipes are driven down into the marl, sometimes with a sledge hammer, far enough to get the water. In some cases, in the northern part of the State, flowing wells have b

River. Mr. W. M. Gregory, of the department of physiography in the Cleveland, Ohio, high school, was employed during July, August, and part of September in the investigation of the northwestern portion of the Saginaw River basin, and also of flowing-well districts in the northern part of the peninsula, in Cheboygan, Emmett, Grand Traverse, Benzie, and Manistee counties, to which he had previously given some attention in connection with stream measurements under Mr. Robert E. Horton. Mr. M. L. Fuller, of the Geological Survey, under whose direction the work was carried on, visited several of the men in the field and spent August and part of September in an investigation of the deficiency of water supplies along the Huron River Valley near Detroit and in a detailed study of the flowing wells in four western counties, Oceana, Newaygo, Mecosta, and Osceola. Muskegon County was investigated by Mr. C. D. McLouth, of the department of physics of the Muskegon high school; Kent County, by Mr. J. F. Nellist, a civil engineer of Grand Rapids; Bay County, by Mr. W. F. Cooper, of the State geological survey, and Wayne County by Prof. W. H. Sherzer, of the State Normal College at Ypsilanti, who also furnished the data for the report on Monroe County. Doctor Lane, the State geologist, investigated and reported on conditions in the vicinity of Lansing and also prepared a brief report on Huron County condensed from his more elaborate State report. The present writer's investigations during the last season were chiefly in Sanilac, Lapeer, and St. Clair counties, on the eastern border of the State, and in Charlevoix, Antrim, and Benzie counties, in the northwestern part. Mr. S. J. Lewis, of the United States Geological Survey, was detailed for a special investigation of the quality of waters and spent about a month in the State, in January and February, 1905, during which time he made about 90 analyses. Dr. V. C. Vaughan, dean of the medical school of the University of Michigan, kindly placed at the disposal of the Survey a large number of analyses made for sanitary purposes but including determinations of hardness, chlorides, and sulphates. Field analyses were also made by Messrs. Fuller, Gregory, and Bowman, which will be found in connection with their reports, herewith presented. Reports were submitted by all those engaged in this investigation with the exception of Mr. Udden, who merely turned in his tabulated data and notebooks. Much work, however, was necessary in order to bring the several reports to a more nearly uniform standard and the present writer has amplified portions, inserted additional data at many points, and supplied most of the geologic and other general descriptions. The several reports, however, naturally differ somewhat in mode of treatment according to the personal standards of the individual writer.

upon springs and surface waters, while about 1,625,000, or two-thirds of the State's inhabitants, depend upon private wells.

There are 37 towns on the borders of the State with a population of about 510,000 which obtain public supplies from the Great Lakes and their connecting streams, St. Marys, St. Clair, and Detroit rivers. The metropolis, Detroit, with a population of about 300,000, is among the number. The water from this source is not so hard as from the majority of the wells, and is therefore especially suitable for boiler use. In an unfiltered state it is often found to be unwholesome and in some cases dangerous for drinking because of contamination in the vicinity of intake pipes. The worst epidemics of typhoid in the State have prevailed in towns taking their supply from this source. It is therefore incumbent on the cities and villages thus situated to put in filtration plants with up-to-date methods of purification. Indeed, all surface water, including that from springs, streams, and inland lakes, should be properly filtered before it is used for drinking or other domestic purposes.

Many of the inland towns have taken public supplies from the streams and inland lakes, the population of such towns aggregating about 300,000. In not a few cases, however, the domestic use of the public supply is largely restricted to closets, baths, and lawn sprinkling, while private wells are used for drinking, there being considerable prejudice against drinking the public supply, not alone for fear of its contamination, but because it is less palatable than the well water. This is especially true in hot weather, when the surface water becomes too warm to readily quench thirst. The streams and lakes are seldom rendered objectionable for drinking because of a muddy condition due to freshets, for on account of the prevalent porosity of the soil the rainfall is absorbed and, except in clayey districts, is largely supplied to streams by underground seepage. Only the most violent rains cause much disturbance of the streams. Michigan is more highly favored in this respect than the neighboring States.

Of the cities drawing public supplies from wells only 5 had in 1900 a population of more than 10,000, namely, Jackson, Kalamazoo, Lansing, Ann Arbor, and Manistee. The supply at Jackson is from deep wells in sandstone and probably is not excelled by any city in the State. Lansing also obtains its supply from sandstone. The three others obtain supplies from glacial deposits or from the overlying gravel. Many smaller cities, the majority of villages with public supplies, and several of the State institutions are entirely supplied from wells, there being 29 using wells in rock, and 104 using wells in the drift, while 15 others are supplied in part from wells and in part from surface water. The rock wells are chiefly from sandstone, those from limestone being almost wholly restricted to the Northern Peninsula and to the northern part of the Southern Peninsula. Many data concerning the public as well as private supplies from wells will be found in the special reports herewith presented.

just mentioned, on the northwest by an equally prominent morainic belt, and on the southwest by moraines of less prominence lying in the southern end of the State. During the retreat of this ice lobe there were halts at several lines which are marked by small morainic ridges. These small ridges serve as catchment areas for flowing-well districts on the inner or iceward border of the moraines.

West of the district covered by the Saginaw ice lobe is another rolling belt of country running from the southwestern part of the State northward nearly to Grand Traverse Bay. Like the belt in the southeastern part of the State, this contains numerous small lakes. Its altitude ranges from about 800 to 1,700 feet, the highest point being a few miles south of Cadillac, in northern Osceola County, near latitude 44° 15′ and longitude 85° 20′. This is by far the highest point in the Southern Peninsula, there being few others which exceed 1,500 feet. This belt was formed between the Saginaw ice lobe and a still larger ice lobe occupying the Lake Michigan basin. It is a catchment area for flowing-well districts on each side and there are also depressions in it found to be favorable points for the development of flowing wells. This belt is crossed by the principal rivers of southern Michigan (the Grand, Kalamazoo, and St. Joseph), while Muskegon River has its source in it in the north-central part of the State, and leaves it only a few miles before entering Lake Michigan.

Along the eastern border of Lake Michigan, from the southern end of the State northward to Oceana County, or to about the middle of the western border of the southern peninsula, the country is genrally low for a few miles back from the lake, with the exception of a strip of dunes formed adjacent to the present beach. But from Oceana County northward to the Strait of Mackinac there come out to the lake shore at frequent intervals headlands which are the termini of prominent ridges that form or connect with moraines a few miles back. The low tracts between these headlands are favorable places for the development of flowing wells.

The interior of the northern half of the Southern Peninsula is an elevated tract in which extensive sand plains have been developed in connection with the moraines. On these plains and on some of the moraines connected with them there formerly stood extensive tracts of pine forest, now largely cut away. Since the lumbering days the plains have been developed somewhat for agriculture, but are still in large part very sparsely settled.

On the northeastern border of the peninsula, from near Alpena to the Straits of Mackinac, rock ledges become conspicuous as a topographic feature, but elsewhere in the State they are subordinate to the glacial features outlined above. The rock ledges have low escarpments facing the northeast, along the base of which are occasional small lake basins. The drift in this region is thin, and wells are consequently largely in rock.

ond about the mouth of the Raisin extending southwestward into Erie Township, and a third in eastern Berlin Township. The flow of water is exceptionally strong in some of these wells. Thus, at the Greening Brothers' nurseries, south of Monroe, the water reaches the surface with force enough to run sprinklers, and has a head of at least 12 feet. Eastward, at Lake Erie, at the Lotus House, are two flowing wells in which the water will rise 20 feet above the surface, or 25 feet above the lake. The heaviest flow of artesian water in this belt was struck in September, 1899, on the south bank of Otter Creek, 2½ miles southeast of Lasalle, at the residence of Edward Sharkey. The well is 51 feet deep and enters rock 6 to 8 feet, and has a diameter of 3 inches. The water came with such force that when a plug was driven into the pipe, which prevented it from escaping freely, the water began to rise through the clay around the mouth of the well and formed a shallow lake about 100 feet across. The plug was afterwards withdrawn and an 8-inch pipe inserted, from which a stream 2 feet broad and 4 inches deep flowed to Otter Creek.

MIDDLE ARTESIAN BELT.

The middle belt consists of three detached areas extending in a northeast-southwest direction across the county. The southernmost is a narrow area, 3 miles long by half a mile wide, in Bedford Township east of Lambertville. The head is slight, the highest rise noted being about 6 feet. The most northern area of this belt is in northeastern Exeter and northwestern Ash townships, where a rise of 3 feet above the surface is about the limit. The water usually contains hydrogen-sulphide gas, and some of the wells proved so offensive that they were plugged. In northeastern Ash Township and northwestern Berlin Township the wells, as noted in the report by Fuller, have nearly all ceased flowing. The portion of this middle belt in the central part of the county is a large irregular area over which flows are scattered, occurring ordinarily only on the lowest ground.

MILAN-CONE DISTRICT.

This district lies in the northwestern township of the county and occupies a strip less than 1 mile wide and about 6 miles long, leading from the village of Milan southwestward past the village of Cone. Some of the wells have been flowing about fifty years, and show no marked decrease, but the water rises very little above the surface. Indeed, the flows are confined chiefly to a low strip lying under a beach line, where the surface had been cut a little below the general level of the plain. Immediately back of this beach to the west the water rises to an altitude greater than that at the flowing wells, but not quite high enough to come to the surface. Still farther west is a flowing-well district which touches the northwest corner of Monroe

County, but lies largely in Lenawee and Washtenaw counties, and is discussed under the Lenawee County supplies.[a] This district was included by Sherzer with the Milan-Cone district.

The flowing wells of the district, of which tabulated data are presented below, all fall within Milan Township. The distance to rock increases from about 40 feet in the southeastern part to 150 feet or more in the northwestern. This is due partly to an increase of altitude to the northwest, the southeastern part being 650 feet and the

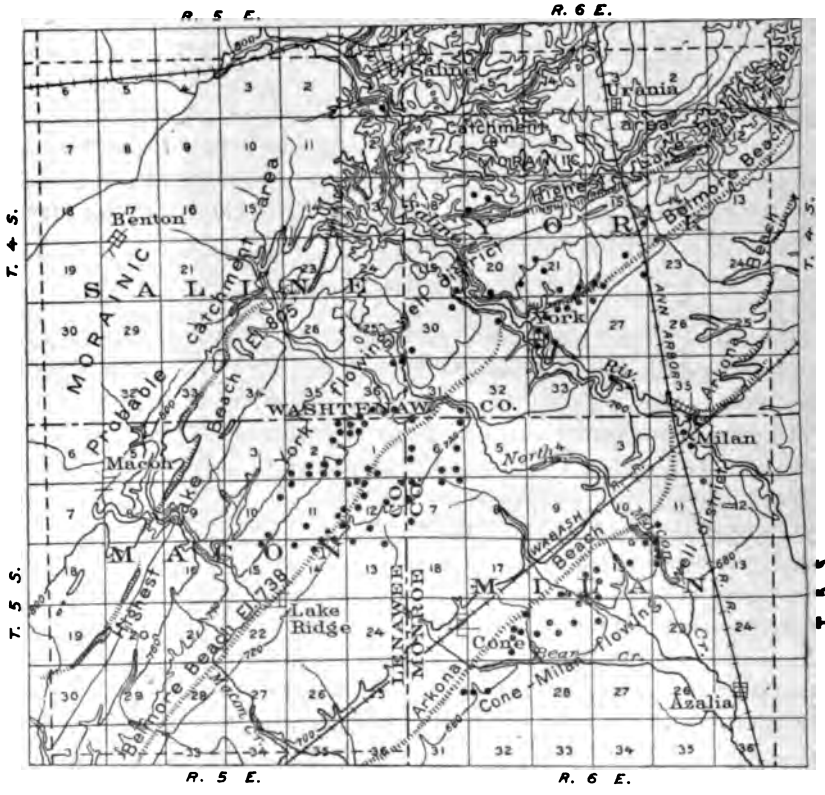


FIG. 4.—Map of York and Milan-Cone flowing-well districts.

northwestern 740 feet above tide. The township is sand covered only in the eastern part, and there the wells are shallow, as in London Township. Elsewhere the wells generally find supplies without reaching rock at depths ranging from 25 to 150 feet. A few wells have been drilled into rock on the borders of the flowing-well district with a view to obtaining a flow, but adequate supplies of water were found in the drift. The flowing wells of the extreme northwest corner of the township are discussed in the report on Lenawee County.[a]

[a] See York flowing-well district, pp. 82–86.

Wells of Milan-Cone district.[a]

	Part of section.	Owner.	Depth.	Elevation.	Water rises to—	Remarks.
			Feet.	*Feet.*	*Feet.*	
2	NE. ¼	T. A. Wilson	40	680	688	Strong flow; south of Saline River.
2	NE. ¼	A. Van Wormer	40	680	682	Weak flow; south of Saline River.
2	NE. ¼	C. M. Blackmar	20±	680	688	North side of Saline River; about 20 feet in depth; flows weak to moderate.
2	NE. ¼	J. & E. Gauntlett	20	680	688	
2	NE. ¼	H. C. Sill	20	680	688	
2	NE. ¼	W. N. Reeves	20	680	688	
2	NE. ¼	A. J. Mesic	20	680	688	
1	NE. ¼	R. C. Allen	55	682	685	Well in shallow sag.
1	SW. ¼	S. Campbell	35	682	685	Made about 50 years ago.
4	NW. ¼	A. Shafer	60	680	685	Moderate flow; water chalybeate.
4	W. side	Warren Lewis	70	682	685	Three flowing wells, 60, 61, and 70 feet; moderate flows from sand below till.
4	SW. ¼	C. Reeves	67	678	676	Strong well; soft water.
5	N. side	(?)	(?)	685	690	
5	NE. ¼	Wm. Lee, jr.	40	680	685	Well made about 1870; moderate flow.
5	E. side	Mrs. L. VanWormer	(?)	682	685	Strong flow; made many years ago.
5	SW. ¼	N. Holcomb	75	680	685	Strong flow.
5	W. side	(?)	(?)	685	690	Two strong flows.
6	E. side	(?)	(?)	685	690	Do.
6	S. side	Thos. Welch	60	685	699	Two flows, now choked with sand; one 3-inch well made 25 years; the other 1-inch well made 18 years ago.
0	E. side	Erastus Cone	25±	684	692	Pioneer well, made over 50 years.
0	E. side	John Denison	30	690	692	Good flow for the altitude.
0	SE. ¼	(?)	10	682	690	Two flows, one at only 10 feet, another a few feet deeper.
1	E. side	Henry Wilcox	84	685	687	Two weak flows, 79 and 84 feet, from sand below till; water soft.
1	Center	T. Caswell	75	682	690	Strong flow.
1	W. side	H. Downing	75	685	690	
1	W. side	George Auten	26	685	690	Flows 3 gallons per minute from 1-inch pipe 3 feet above ground; has been flowing 50 years.
1	SW. ¼	Alvin Cone	25	680	690	Strong flow.
2	W. side	Mrs. P. Nolan	35	680	685	Not in use.
8	NW. ¼	Alvin Cone	60	680	685	Weak flow.
8	W. side	A. Vanderwenter	28	679	675	Pump well.
9	N. side	do	60	680	685	Flow in field.
9	N. side	Jacob Curry	60	680	685	Do.
9	W. side	Peter Tingley	50	680	685	
9	W. side	Frank Packard	54	682	685	Water from sand under cemented crust below till.
0	E. side	Thos. Caswell	54	682	685	Water from sand below till.

[a] Data collected by Leverett in 1903.

London Township, which borders the Milan-Cone district on the st, is largely sand covered and has few deep wells. The distance rock ranges from 20 to more than 100 feet, the drift being thickest the northwest corner. So far as ascertained, no flowing wells have en obtained in the township. The ordinary depth of wells is about feet; but some along the north border reach 50 to 60 feet and enter ck. There are also a few rock wells scattered over the township.

WELL DATA BY TOWNSHIPS.

The tabulated well records given below were collected and arranged y Prof W. H. Sherzer. They show conditions at the time of his udies, which were completed in 1899. In some townships only eneral statements are furnished.

Wells of Monroe County—Continued.

DUNDEE TOWNSHIP (T. 6 S., R. 6 E.).

[Rock usually at 30 to 40 feet, but sometimes 11 to 70 feet or more; depth of wells 10 to 103 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
			Feet.	*Feet.*	
7	.....	Stephen Ball.....	93	65	Sulphur water, probably from rock.
8	.....	J. Hiser.....	72	72	40 feet of water; drift all clay.
10	.....	Erwin Smith.....	64	58	40 feet of water; from rock.
15	.....	A. Richards.....	62	48	
20	.....	Wm. Hazen.....	103	70	Sulphur water; some gas at 20 feet.
22	.....	R. Ingersoll.....	40	38+	Weak well with iron and sulphur.

SUMMERFIELD TOWNSHIP (T. 7 S., R. 6 E.).

[Wells in surface sand, 14 to 16 feet deep; near base of drift, 40 to 62 feet deep; in rock 70 to 97 feet or more. Depth to rock, 20 to 60 feet.]

4	.....	E. W. Cornell.....	40	40	Water from gravel.
5	Center.....	L. Plumodore.....	70	45	Water from rock, has sulphur and iron.
18	.....	C. L. Goodrich.....	77	58	A little gas.

WHITEFORD TOWNSHIP (Tps. 8-9 S., R. 6 E.).

[Deepest drift south of Ottawa Lake; shallow wells in sand have soft water; deep wells both in glacial deposits and rock; depth to rock 0 to 100 feet; water hard; no burning gas and little H_2S gas; many sink holes; wells often at base of drift.]

5	.....	Chas. Steffins.....	73	20	
8	.....	John Pettit.....	100	.....	Sink hole in limestone on same farm.
17	.....	Wm. E. Jenne.....	72	26	Rock at 9 feet 20 rods southeast.
18	.....	Chas. Jacobs.....	80	18	Strong in sulphur.
19	.....	J. Kummerow.....	116	.....	
20	.....	Fred Aldrich.....	114	20	
28	SW. ¼.....	.....	40	12	
29	SW. part...	G. Lovewell.....	104	24	Sweet water; limestone at 30 feet; shale 55 feet.
30	.....	.....	122	25	Hard rock called "flint," and sandstone.
34	.....	Mill.....	42+	0	Rock near surface for ½ mile radius.
33	.....	D. Dolby.....	60	6	
[a]5	.....	F. Gibbs.....	75	22	Soft and crumbly rock.

[a] T. 9 S.; all the others in T. 8.

IDA TOWNSHIP (T. 7 S., R. 7 E.).

[Good wells easy to obtain; rock in places very near surface near Ida and Lulu villages; flows on east side of township; depth of wells 10 to 48 feet; depth to rock 3 to 32 feet.]

3	SE. ¼.....	R. Gregory.....	.....	32	
4	SE. ¼.....	Julius Frank.....	27	23	
7	SE. ¼.....	C. Hausen.....	11	.....	Well in sand.
9	NW. ¼.....	K. Vogelsang.....	20	12	
10	.....	Chas. Stoty.....	36	30	Hard water from rock.
11	SW. ¼.....	L. Hutting.....	30	20	White sand (rock?) yields water.
13	SE. ¼.....	Mrs. K. Traub.....	10 18	....	Both wells flow.
14	S. side.....	Billmire.....	26	.....	Hard water; no rock.
15	.....	M. Strabel.....	48	.....	Could not case hole because of sand.
24	.....	Frank Long.....	(?)	(?)	Flowing well; there are several flows in section.

obtained by penetrating the marl a few feet. Conspicuous i are found on the borders of Pine Lake at East Jordan, Sou and Boyne, and on the borders of Intermediate Lake near

STRUCTURE OF DRIFT.

The structure of the drift is intimately related to the conditions that attended the melting of the ice. It is more in Michigan, both on the surface and below, than in a larg of the neighboring States of Ohio, Indiana, and Illinois. States the till, or commingled drift, greatly predominates sand and gravel, or assorted drift, and contains a large pe of fine clayey material. In Michigan sand and gravel forn part of the drift, and much of the till is loose textured. T amount of loose-textured drift seems attributable to the vol discharge of water resulting from the convergence of ice lob best developed on the high portions of the State, which were between the ice lobes. The most clayey portion of the drift in plains bordering the lake basins. On these plains more is found in obtaining adequate supplies of water than in th tracts bordering them. Portions of the plains have a thin of sand deposited in the beds of the Glacial lakes that cover after the withdrawal of the ice, and in these localities ma draw their supply from the surface sand.

Flowing wells are usually found under a bed of clayey d for this reason, as well as because of topographic conditi largest artesian districts are found on the old lake plains. (S

The clayey drift differs greatly in degree of induration at horizons, and the sand and gravel also become cemented a horizons. The induration in the clay or till seems to be l result of secondary changes produced slowly and is in some index of age. The surface till sheet, which is of the Wiscons is generally a soft adhesive clay even where very fine textu well diggers and drillers find very little difficulty in penetr Below this the drift is found to be extensively indurated, excavation is difficult and the till approaches a shale in its re The precise nature of the induration has not been ascertaine thought that much of this indurated clayey drift was depos Glacial stage earlier than the one which formed the upper pa drift, probably the Illinoian stage. In some places a soil between the two sheets of till, showing that an interval s them. The buried soils are much more abundant in Indiana than in southern Michigan, but they have been well borings as far north as Bay and Oceana counties.

Another kind of induration of the drift is very common in well districts. Just above the water bed which yields th

WATER SUPPLIES OF THE LOWER HURON RIVER REGION.

By Myron L. Fuller.

INTRODUCTION.

In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of Huron River, in southeastern Michigan, which up to that time, except for short seasons of drought and resulting weakness, had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes.

In July, 1904, Mr. Leverett made a reconnaissance in the vicinity of Carleton, Flat Rock, Willow, and Waltz, determining the general conditions as regards shortage. In August, the shortage still continuing, the writer visited the field and made a more detailed study of the conditions of the wells and of the causes of their failure, the results of which are presented herewith.

Acknowledgments for certain geologic and well data are made to Dr. A. C. Lane, Mr. Frank Leverett, and Prof. W. H. Sherzer. Thanks are also due to Mr. James Swan, of Detroit, owner of the Grosse Isle well, and to Mr. Edward Ready and other residents of Carleton for courtesies rendered.

GENERAL STATEMENT.

The region in which the shortage of water in 1904 was earliest felt, and in which it was severest, is a belt perhaps 10 miles wide along the borders of Wayne and Monroe counties, extending in a northwest-southeast direction about 20 miles, parallel with and including Huron River, and reaching from a point near New Boston to the mouth of the river at the head of Lake Erie. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. The shortage was most pronounced along Swan Creek, which parallels Huron River at a distance of 3 to 5 miles on the south. South of Swan Creek the wells are affected only for a short distance, usually not more than 2 or 3 miles.

The villages principally affected are Willow, Waltz, Carleton, Flat Rock, and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

The entire region is very flat, and the stream channels are shallow. The soil is generally clayey, although locally the clay is overlain by thin sheets of sand, which in places take the shape of low, flat, northeast-southwest ridges representing old beach lines of the lake

which formerly covered the region. The sand has also been shaped in places into ridges by the wind. The country has a gentle slope southeastward toward Lake Erie, usually not exceeding 5 feet to the mile, and this governs the stream courses.

The climate is tempered to a certain extent by the proximity of Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39°, the average maximum 57°, and the average mean 48°. The rainfall, which is about 30 inches, is low compared with the most favored portions of the State, where it reaches 35 to 40 inches, and is less than on the headwaters of Huron River. Normally the rainfall is lowest in January, when it is less than 2 inches a month, and highest in May and June, when it exceeds 3.5 inches a month.

GEOLOGY.

SURFACE MATERIALS.

The material overlying the rock in the region consists of a clay with an admixture of sand and pebbles, technically called till, which is not usually arranged in definite layers as in stratified deposits, but is a heterogeneous mixture, although occasional beds of quicksand or gravel or even scattered bowlders may occur. In consistency it is tough and clay like, and is of a grayish-blue color when fresh, but becomes yellowish through oxidation of the iron on exposure to the weather at the surface. Some surface bowlders occur in the part of the area nearest Detroit River.

Although having a flat surface, the thickness of the drift varies because of differences in the elevation of the underlying rock surface, which reaches much nearer to the top of the ground in some places than in others. The clayey deposits are 15 to 60 feet or more in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and may even have cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface, as at the large quarries at Newport.

In a broad way the thickness of the clays may be said to increase as Detroit River and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 60 feet, while near Rockwood it may be equally great.

The bowlders and the unstratified materials were derived from the ice sheet which once invaded the region or from a succession of such invasions, but the pockets and thin beds of gravel and sand which are included were deposited by water, perhaps in some cases simultaneously with the glacial deposits, while the sand beds which cover portions of the drift surface are the product of lakes which occupied the region after the retreat of the ice.

ROCKS.

The rocks underlying the clays in the lower Huron River region sist of limestones, sandstones, shales, etc., arranged in belts ending in a northeast-southwest direction, or at a right angle to course of Huron River. They are reached by all but the shallow g wells, and afford the greater part of the ground water found in region.

In the northwestern portion of the area, or beyond a point a couple miles northwest of Carleton, the rock is the Dundee limestone, a rly pure, light-colored, flint-bearing Devonian limestone, perhaps 0 feet in thickness, dipping northwestward 20 to 25 feet to the ile. It is characterized by waters more or less charged with lphur in the form of hydrogen sulphide.

Below it lie the upper Monroe beds of drab Magnesian limestone r dolomite, sometimes carrying sand, gypsum, and other minerals. he dip is similar to that of the Dundee limestone. The waters are ard, but are not characterized by much sulphur.

Next below is the Sylvania sandstone, a white sandstone outropping beneath the clay from a point about a mile east of Carleton early to the mouth of Huron River. The dip is somewhat flatter an that of the preceding formations, and is more to the north than the northwest. It yields water of good quality.

Last are the lower Monroe beds, which are generally similar to the mestones and dolomites constituting the upper part of the Monroe eds already described, but are often more siliceous than the latter. hey outcrop parallel to the Sylvania sandstone in a narrow belt long Lake Erie and Detroit River. Their waters carry some lphur.

WATER SUPPLIES.

Within the region under discussion the water supplies vary conderably in composition, head, volume, and shortage in time of rought. The wells are dug, drilled, or a combination of the two. he flowing wells may be grouped in four areas: (1) Willow-Exeter; 2) Swan Creek; (3) Huron River; (4) Rockwood.

WILLOW-EXETER REGION.

The name Willow-Exeter region is applied to the area now or ormerly furnishing wells, which extends from the vicinity of Willow outhwestward past Waltz into the northeastern part of Exeter ownship, Monroe County (in secs. 1, 11, 12, 13, and 14, with parts f secs. 2, 10, and 15). The belt lies transversely to the drainage f the region and is located mainly over the outcrop of the Dundee imestone.

The dug wells obtain a very limited supply of nonsulphur water from the clays and associated gravel and sand. The drilled wells pass through the clay and permeate the rock sufficiently to obtain water strong in sulphur, which will frequently flow at the surface. The combined dug and drilled wells are usually dug about 15 feet and a small drill hole continued from the bottom down to the rock, which is usually penetrated a foot or two. Such wells are particularly adapted to those cases where the water will rise nearly but not quite to the surface. They furnish opportunities for storage and will ordinarily yield more water than the simple pipe wells, for the latter may become clogged when water is most needed.

The depth of the wells varies from about 15 feet to 55 or 60 feet, of which usually all but a foot or two is through clay. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams or in sags of the surface that good flows are obtained.

The portion of the district near Willow was visited on July 18, 1904, by Mr. Leverett, who furnished the data in the following paragraph:

Extending a mile or more both to the east and west of Willow is a line of flowing wells averaging 60 feet in depth and obtaining sulphur water. They all draw from the same horizon and have always interfered more or less with one another. The flowing well of Henry Ludwig, on the west side of the NW. ¼ sec. 28, which penetrated 50 feet of clay, etc., with a crust at its base before entering the rock seems to have had a marked effect on the wells near the village of Willow, reducing their head, or even, in some cases, stopping the flow altogether. The later wells in Willow have reduced the head of those earlier made, both in and west of the village.

The following table presents the main data collected by the writer:

Wells in Willow-Exeter region.

Town-ship.	Range.	Section.	Part of section.	Owner.	Depth.	Head. Maximum.	Head. Present.	Shortage noted.	Remarks.
					Feet.	*Feet.*	*Feet.*		
5	9	17	SW. ¼	R. Woodward	16	.....	8	.....	Typical well in clay; no shortage.
5	9	18	SE. ¼	J. J. Lucke	45	+20	+20	.....	Typical sandstone well; good water; no shortage.
5	9	20	NW. ¼	J. S. Ankerbrandt	21	+10	+17	June	Tiled well; rolly before storm.
5	9	20	Center	Frank Woodward	.....	.....	.....	.....	Two wells, type unknown; both dry.
5	9	19	NE. ¼	George Burgess	18	+6	+10	.....	Sandstone well; plenty of water left.
5	9	18	SW. ¼	Frank Dusheck	33	+0	12	.....	Plenty of water by pumping.
5	8	13	SE. ¼	John Wenzel	41	+6	6	.....	No shortage; sandstone water.
5	8	13	NE. ¼	James Dunn	.....	+1	+3	July	Plenty of sulphur water; a surface well; goes dry every season.
5	8	13	SW. ¼	J. Crimins	.....	+3	+3	.....	Sulphur water: went dry in spring, but water returned on cleaning.
5	8	13	NW. ¼	Henry Kingsley	28	+0	+2	July	Sulphur water: another well still flows.
5	8	13	Center	Edw. Navarre	.....	.....	.....	.....	Lowered, but still plenty.
5	8	14	NE. ¼	Frank Ochs	28	±0	±0	1902	Plenty of sulphur water, but less than before 1902; no recent shortage.

Wells in Willow-Exeter region—Continued.

Range.	Section.	Part of section.	Owner.	Depth.	Head. Maximum.	Head. Present.	Shortage noted.	Remarks.
				Feet.	*Feet.*	*Feet.*		
8	24	.....	John Theisen.....	.....	.....	.....	.....	Good flow just struck.
8	14	Center..	D. Livernois.....	20	.....	.....	.....	No sulphur; plenty of water.
8	14	Center..	F. Maynes.....	30	+ 3	+ ½	.....	Sulphur water; no recent decline.
8	14	Center..	Philip Zink.....	30	− 4	− 4	.....	Sulphur water; as much as usual.
8	14	NW. ¼..	F. Maynes (field)..	33	.....	+ 0	.....	New sulphur well.
8	10	SE. ¼...	J. W. Zink.....	37	− 3	− 8	.....	Always improved by cleaning.
8	11	SW. ¼...	John Murphy.....	35	+ 0	− 8	.....	Sulphur water; failed once, but flowed again on cleaning.
8	2	SW. ¼...	C. S. Davis.....	.....	.....	.....	.....	Fresh and sulphur well; no unusual shortage.
8	11	NW. ¼..	A. W. Dexter.....	.....	.....	.....	.....	Do.
8	2	S. side..	A. Fay.....	.....	.....	.....	.....	Do.
8	1	SE. ¼....	M. Vasher.....	32	+ 4	+ 3	.....	Sulphur water; weakened, but supply returned on cleaning.
8	1	SW. ¼...	F. Livernois.....	.....	.....	.....	.....	Stopped at first, and permanently weakened by Vasher well.
8	12	SW. ¼...	Wm. Ganos.....	40	− 9	− 9	.....	No change; sulphur water.
8	12	SW. ¼...	Sam Ganos.....	44	− 3	− 3	.....	No change; sulphur water; surface wells dry.
9	7	SW. ¼...	Joseph Discher....	.....	− 8	− 8	.....	No shortage; surface wells full.
9	18	NW. ¼..	C. Heinzerling.....	28	−14	−16	.....	Sulphur water; no unusual shortage.
9	7	SE. ¼....	J. J. Lucke.....	22	− 3	−18	1903.....	Sulphur well; improved by cleaning; surface wells all right.
9	7	NE. ¼...	J. H. Jewell.....	.....	− 0	− 3	Spring..	Sulphur water; flowed up to May.

An examination of the above table will show that the conditions e not uniform. Several surface wells are reported dry, while in hers the supply seems to be the same as usual. No decrease is ted in the wells in the sandstone, and most of the limestone wells ielding sulphur water) show little, if any, material shortage, although ners report losses which in several instances were returned wholly in part after cleaning. Some interference exists.

The shortage appears to be such as would accompany an unusually y season. The moderate decrease due to drought has not been iform, but was felt first by the shallower wells, or by those yield- g small supplies, and last by the deeper and stronger wells. The ference is generally most noticeable in the flowing wells, for a ference of a foot or two in head may determine whether a well will w. Shortage in previous years is reported.

The elevation to which the water will rise declines from 622 feet ove sea level in the western part of sec. 14, T. 5, R. 8, to 600 feet ar the east line of sec. 19, the next township east, or a little over eet to the mile. This indicates a source of supply from the west, obably not more distant than the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of nonflowing wells, lying between the Willow-Exeter and Swan Creek flowing-well districts. The wells are commonly about 30 to 35 feet deep and probably enter a few feet into the Sylvania sandstone, from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August, 1904, although the wells were somewhat lower than usual.

SWAN CREEK REGION.

The Swan Creek region is one of flowing wells extending southeastward along the valley of Swan Creek from near the Detroit Southern Railroad 1½ miles northeast of Carleton to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron River and Rockwood flowing-well districts. This is mainly over the outcrop of the Sylvania sandstone.

The drilled wells obtain their water on entering the rock, after passing through stiff impervious clays, and have hitherto yielded good flows of nonsulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

The data relating to the condition of the wells is most conveniently presented in the form of the table given below; besides the wells of the district proper, or flowing-well area, a few located a mile or so outside are given:

Wells in Swan Creek region (T. 5 S., R. 9 E.).

Section.	Part of section.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
				Maximum.	Present.		
			Feet.	*Feet.*	*Feet.*		
17	SE. ¼	John Cequin	33				No decrease; suggests ditching as cause of shortage in other wells
20	NE. ¼	Henry Spicer	35				No decrease.
21	SW. ¼	Albert Spicer	30				Two wells; no decrease in rock well; surface well failed.
20	SE. ¼	Wm. Sillmore	30			June	Just to rock (surface well); failed
20	SE. ¼	L. Graves	37			March	Low; cleaned without result.
21	SW. ¼	J. J. Lautenschlager	32				Dug 18 feet; water only in pipe.
28	NE. ¼	Sam McLaughlin				June	To rock only; three wells; all went dry; little better after cleaning.
28	NE. ¼	B. McLaughlin	26	± 0	− 0	Spring	Flowed 30 years ago; dug 8 feet; water in pipe only.
22	SW. ¼	Frank Bergmoser	22	+ 0	− 0	May	Nearly dry; always plenty before
22	SW. ¼	do	28			April	Dry; has failed before.
22	SW. ¼	do	27			May	Dug 13 feet; water in pipe only.
21	SE. ¼	Henry Hood	28	−10	−16	Aug	Deepened with success; another lower well stopped flowing.
28	SE. ¼	Mrs. P. Kelly					Nearly enough water.
28	SE. ¼	Ed C. McCormick	30	− 5	−11	June	Loss ascribed to frozen ground and Newport quarry; improved by cleaning.
28	SE. ¼	B. McLaughlin					No trouble with wells.
32	NE. ¼	Joseph Esper	20	− 3	−15	June	Surface well; loss ascribed to frozen ground.

Wells in Swan Creek region (T. 5 S., R. 9 E.)—Continued.

Section.	Part of section.	Owner.	Depth.	Head. Maximum.	Head. Present.	Shortage noted.	Remarks.
			Feet.	*Feet.*	*Feet.*		
27	S. side	J. Funerstalk	35	−10	.....	Spring	Dug 12 feet; water in boring only
26	NW. ¼	Mr. La Ranger	.....	− 4	− 4	.....	No change; large supply
23	NW. ¼	C. Muth	21	− 6	−10	.....	Low, but still plenty of water.
25	NE. ¼	George Calkins	21	− 5	−10	.....	Enters slowly, but plenty of water.
25	SW. ¼	Nicholes Noel	14	−12	−13	.....	Surface well; a little less water than usual. Two other smaller wells in vicinity get plenty of water.
25	SE. ¼	E. H. Van Tassel	.....	.....	.....	.....	To rock; no decrease noted.
25	SW. ¼	W. M. Swype	20	−10	−19	July	At barn; never dry before. Drilled wells at house as much as usual.
25	NW. ¼	Wm. Southworth	33	− 6	− 6	.....	No trouble; one well used to flow.
24 / 25	W. side / E. side	S. Uden (3 wells)	.....	.....	.....	.....	On line between secs. 24 and 25. Two wells out of three failed.
26	NE. ¼	Peter Bitting	27	− 8	−10	.....	Plenty of water; another well the same.
23	S. side	B. Parish	27	+ 4	+ ½	June	In field; has been low in August of other years.
23	S. side	.....do	30	− 4	− 8	....do	At house; has been low in August of other years.
23	S. side	Ed. Parish	22	+ 2	−15	July	Failed suddenly; three similar wells.
23	SW. ¼	Schoolhouse	25	+ 0	− 0	May	Flowed during summer of 1903.
23	SW. ¼	J. McCollum	29	8	−13	June	Still yielding water.
23	SW. ¼	.....do	15	+ 0	+ 0	.....	New well near creek.
22	NE. ¼	G. A. Harpst	29	4	−14	Aug	Very low; loss ascribed to Grosse Isle well.
22	NE. ¼	Earl Baker	28	5	.....	.....	Water in pipe only.
(?)	(?)	Tony Kahn and Charles Kruger.	.....	.....	.....	.....	Still yielding some water.
22	SE. ¼	J Hedges	.....	+ 0	− 0	June	Still yields some water.
22	SE. ¼	A. Benedict	.....	+ 0	− 0	.....	Water now stands just at top of pipe.
15	E. side	Eli Barrow	.....	+ 0	− 0	.....	Near creek; well at house also failed.
14	W. side	Edward Whipple	.....	+ 0	−18	June	Plenty of water by pumping; loss ascribed to Grosse Isle well.
15	E. side	Mark Baker	.....	+ 0	− 0	.....	Slight decrease; ascribed to Grosse Isle well.
15	NE. ¼	G. Schweitzer	18	− 0	− 3	.....	Near creek; well at house also lowered, but improved by deepening.
14	SW. ¼	F. Baker	.....	+ 0	− 0	1902	Less than usual, but plenty.
23	N. side	D. Reed	.....	.....	.....	.....	Failed, but got plenty by going 2 feet deeper.
23	N. side	H. Gretzler	32	− 5	−11	July	Another well at house failed; plenty of water by cleaning.
23	NE. ¼	Barnard Parish	33	− 7	−12	May	Supply sufficient; similar well across road.
13	SW. ¼	C. M. Hood	35	− 6	−12	.....	More water by deepening; another well dry.
13	NW. ¼	F. Reinhart	35	.....	−12	.....	New well; failure of old ones ascribed to Grosse Isle well.
13	NW. ¼	A. Vizard	35	− 6	−11	.....	Another similar well; supply sufficient; water also in dug well.
12	SW. ¼	J. F. Smith	.....	.....	.....	.....	Enough water for cattle.
11	SE. ¼	Henry Green	30	− 4	.....	June	Dug 8 feet; water in pipe only; very low.
11	SE. ¼	Irvin Barnum	28	− 5	.....	May	Dug 8 feet; water low in pipe.
14	NE. ¼	W. Baker	.....	− 8	.....	.....	Surface well; water by going 7 feet deeper.
14	NW. ¼	Emily Clark	30	− 8	.....	Spring	Scanty supply.
11	SW. ¼	Fred Renton	37	− 5	−13	June	Got more water by going 8 feet deeper.
11	SW. ¼	C. Stumpmeyer	.....	− 6	−13	May	Three wells, 32, 33, and 35 feet deep, nearly dry; cleaned without success; no previous trouble.
10	SW. ¼	M. Reeves	.....	.....	.....	.....	Near creek; failed; always plenty before.
10	SE. ¼	G. W. Reeves	.....	+ 0	− 0	1902	Another well just to rock has sufficient for ordinary use.
10	SW. ¼	J. E. Brown	22	+ 0	− 0	1902	Failed temporarily in August, 1903, and again in spring of 1904.
16	.....	Floyd Barnum	.....	− 5	−15	.....	Cleaned with little effect.
9	.....	Alex. Todd	20	+ 0	− 0	Spring	Plenty of water by pumping.

In the Swan Creek region nearly every well shows shortage, though the decrease is not uniform, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very commonly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while in others the water, though still running, rises to only a part of its former height. In the non-flowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination of dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued above the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly in the spring of 1904. Just at what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Several remedies were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening was resorted to. In some cases the dug part was carried a few feet deeper, and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective result was obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although of course it had to be pumped to the surface. Probable causes for the shortage are considered below in the discussion of the entire field affected.

HURON RIVER REGION.

The Huron River district extends along Huron River from a point a mile or two southeast of New Boston downstream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The rock is largely Sylvania sandstone, except at the northern end of the district. The wells range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water which is nonsulphur bearing.

No special investigation was made in the New Boston part of the a this season, but the conditions are reported to be similar to those the Willow-Exeter field, there being relatively little shortage. ne of the wells have, however, stopped flowing, but this is not racteristic of the present season alone. The well of Gus Miesner, the SW. ¼ sec. 9, formerly yielded a flow between 60 and 70 feet, but now ceased flowing. Near the schoolhouse, on the west side of . 15, a well owned by Mr. Blum flowed a 4-inch stream of sulphur ter when first sunk in 1887, but now flows less than 1 gallon a nute. The well is 65 feet deep. South of the schoolhouse Julius hn sunk a well in 1891 to a depth of 65 feet. This flowed at the rt, but soon after ceased.[a]

In the region between the bridge 2 miles east of Willow and Flat ck most of the wells are still flowing, although some have ceased. rth of the river the Horace Thompson well, in the southeast part Huron Township, is still flowing sulphur water, after a lapse of rty years, though at a level 1½ feet lower than usual. The depth the well is but 26 feet. In sec. 26 Mrs. Lawrence has a very weak wing well of "black sulphur" water. In the northwest quarter the same section Mr. Stoefflet sunk a well in June, 1904, to a depth 96 feet, obtaining a full 2-inch stream of water. The well drained hers for a quarter of a mile north and west and had to be plugged. uth of the river the conditions are very similar; some wells have ased flowing while others continue, though with diminished head.[b] In a broad way it may be said that there is a general shortage in e region, but not so severe as in the Swan Creek district, for along e Huron many wells still furnish good supplies, or even flow, while in e latter region the failure is almost universal. Cleaning and, more pecially, deepening the wells generally resulted in an improvement of conditions, though not in a complete restoration of the pply.

ROCKWOOD REGION.

The Rockwood area includes the region west and southwest of that wn and between it and the Swan Creek area, together with the gion near the town on the north side of Huron River. It can be nsidered as merging into the flowing-well areas of Swan Creek and ron River on the west and with the Detroit River region on the st. The area is mainly over the outcrop of the Sylvania sandstone d yields waters generally free of sulphur. The wells are chiefly m 20 to 40 feet in depth and are nonflowing except near Huron

[a] Information furnished by W. M. Gregory, August 2, 1904.
[b] Information furnished by Frank Leverett, July, 1904.

River. In the following table are given data relating to the condition of the wells as determined by the writer in August, 1904:

Wells in Rockwood region.

Township.	Range.	Section.	Quarter.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
						Maximum.	Present.		
S.	E.				*Feet.*	*Feet.*	*Feet.*		
5	8	17	NE...	D. Valrance.....	28	− 1	− 7	May....	Has been dry before; loss ascribed to Grosse Isle well.
5	8	17	NE...	H. D. Valrance....	30	+ 3	−30	.....	Pump gave temporary relief; loss ascribed to Grosse Isle well.
5	8	17	NE...	V. Holmes.....	.....	+ 0	+ 0	May.....	Water in pipe only.
5	8	17	NE...	John Strong.....	.....	+ 0	− 0	.....	Diminished somewhat.
5	8	17	NW...	Royal French.....	30	+ 0	−20	.....	Plenty by pumping.
5	8	18	NE...	George Case.....	.....	+ 0	− 0	.....	Nothing done.
5	8	7	SE....	James Todd.....	36	+ 2	−36	.....	Failed suddenly after 32 years; no water by pumping; loss ascribed to Grosse Isle well. Two other wells ceased flowing.
5	8	18	NW..	John Antio.....	30	− 2	− 8	Spring..	One-fourth ordinary supply.
5	8	7	SW...	S. Peters.....	30	− 6	−12	....do...	Flowing well also stopped.
5	8	18	NW..	Charles Bancroft..	31	+ 0	− 8	1903.....	Two other wells also failed, but came on again during winter. One stopped temporarily during winter, lost again in spring of 1904.
5	8	18	NW..	Benjamin Bancroft.	29	− 5	−25	.....	Two wells, not very low in 1903.
5	8	18	SW...	G. Van Riper.....	36	− 5	−14	July....	Another smaller well. No previous trouble; loss ascribed to salt and oil wells.
5	9	13	SE....	H. Chamberlin....	36	− 5	.....	.....	Water in base only.
5	8	18	SW...	Philip Baully.....	40	− 5	−12	June....	Decreased gradually.
5	8	19	NW..	Peter Pilkey.....	40	− 2	.....	Early...	Low all winter. Water only in pipe.
5	8	20	NW..	Mr. Mattison.....	.....	− 9	−18	.....	Low all winter.
5	8	20	NW..	....do.....	.....	− 5	−10	.....	Do.
5	8	19	NE...	P. Donnelly.....	.....	− 4	−17	.....	Loss ascribed to Grosse Isle well.
5	8	19	SE....	Albert Root.....	22	−10	−14	July....	Usually plenty in summer.
5	8	29	NW..	John Sigler.....	22	− 3	−12	....do...	Do.

The facts set forth show a marked shortage of supplies, with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903, when the present shortage first began to be felt. During the winter of 1903–4 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the individual wells stopped suddenly the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head; hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms, and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest to the west of Rockwood, becoming less near town as Detroit River is approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and Detroit River. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, thickly settled and wells are abundant, probably averaging under 20 feet in depth. In general there has been no shortage, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was fully as high as is ordinarily the case, for Lake Erie, which controls the ground-water level adjacent to its shores, stood unusually high in the summer of 1904, being about 15 inches above its level of the preceding year.

GROSSE ISLE.

Grosse Isle is a north-south island about 9 miles long and 2 miles wide lying on the American side of the international boundary in the Detroit River, its center being opposite the town of Trenton, 16 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being in the interior, although the entire island is under cultivation. The surface is mainly clay or clayey silts, but rock is commonly found not far from river level, and in one point where it rises slightly higher is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of windmills, no provision being made for filtering. As a result there is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and a powerful flowing well recently made at the southern end of the island seems to have had no effect on the shallow wells. This powerful well is located on the property of James Swan, opposite Snake Island, about three-fourths of a mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the river level of 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet, but at 450 feet a stronger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart to the water as it issued from the pipe an amount of sulphur recognizable by taste and by a sulphur deposit on the grass and stones about the well. The water is said to have been cased off during the progress of the drilling, from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable size. (See Pl. III, *B*.) The flow is calculated at about 50 gallons a second and forms two good-sized streams. It was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using it for a public supply for the island.

Analysis of water from James Swan's well on Grosse Isle.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	188	Potassium (K)	79.68
Iron and alumina (Fe_2O_5, Al_2O_5)	14	Sulphate radicle (SO_4)	14,245.21
Calcium (Ca)	5,082.96	Carbonate radicle (CO_3)	871.35
Strontium (Sr)	317		
Magnesium (Mg)	730.57		21,745.55
Sodium (Na)	216.78		

DECLINE OF WATER SUPPLY.

PRESENT CONDITIONS.

The conditions of the wells at the present time have been set forth in the preceding pages. With the exception of the narrow belt along the shore of Detroit River, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very light, while along Huron River it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large proportion of the wells having failed, entailing much inconvenience.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even then shrinkage of supplies had been in progress for many years. In his report on Monroe County[b] he states that while continued drought makes no impression on many of the wells, the flow of others is reduced or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian

[a] Made at chemical laboratory, University of Michigan, for the State Geological Survey, January 17, 1905; F. K. Ovitz, analyst. Expressed by analyst in grams per liter and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] Rept. Geol. Survey, Michigan, vol. 7, pp. 194.

A. LARGE SPRING AT UNITED STATES FISH HATCHERY, NORTHVILLE, WAYNE COUNTY, MICH.

B. VIEW OF THE GROSSE ISLE FLOWING WELL.

wells could be secured was found to be constantly contracting. Wells in the southern part of Erie Township, 3 miles back from the lake, which formerly flowed, had then ceased.

The decline noted by Professor Sherzer as having already progressed for some time has continued. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the nonflowing wells is lower than formerly. In fact, the level of the ground water in the clayey portions of southeastern Michigan is distinctly lower than it was ten years ago and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline which has been going on for many years is probably due to a gradual and far-reaching change of conditions, such as deforesting of the land, improvement in surface drainage, etc., but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

CAUSES OF DECLINE.

Grosse Isle well.—That the Grosse Isle well is the cause of the special decline in 1903 and 1904 may at first thought seem well sustained by the behavior of certain wells, as J. E. Brown's of the Swan Creek and Charles Bancroft's of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned soon after the insertion of the casing, only to cease again after its withdrawal in May, 1904. This interpretation, however, seems opposed by the fact that numerous other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be very exceptional, which would leave a near-by district unharmed while seriously affecting more remote districts, and belief in them would need be supported by indisputable evidence in the altered slope of the water table. In order to obtain light on this point the height to which water will rise was platted for each well in the Swan Creek-Rockwood region. It was found that this height showed an increase westward which averaged about 3 feet to the mile, indicating a source from that direction. The increase of head to the west or decrease to the east was found to be quite regular, with no local lowering or reversed slope that could be referred to a strong intake at a particular place. It was also found that the water level of the Grosse Isle gusher is higher than that of the shallow wells around it, and even higher than that of the wells of

the Rockwood and eastern portion of the Swan Creek area, being 25 feet above the lake, or 597 feet above the sea, while the normal level in many of the wells which have been thought to feed it is several feet lower, in some of them being less than 590 feet. It would appear, therefore, that if any connection exists between the Grosse Isle well and the shallow wells in the Rockwood and Swan Creek areas the water would be forced up in the shallow wells rather than drawn away from them. The failure of such wells as the Brown and the Bancroft flows in 1903 was probably a mere coincidence. The precise point where the main water-bearing bed of the Grosse Isle well outcrops and takes in its main supply can not be stated. On the basis of the dip of the rock formations from southeast to northwest, at the rate of about 20 feet a mile, it would seem probable that the bed struck at 450 feet in this well will come to the surface somewhere west of Leamington in Canada. The supply seems, therefore, more likely to come from the Canadian than the Michigan side of Detroit River.

Newport quarry.—The underdrainage caused by the quarry at Newport was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions were investigated. It was found that a few of the wells near at hand have been affected, but the decrease in water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted. From this it appears that the quarry can not be considered a factor in the shortage along Swan Creek or in the Rockwood region.

Low stage of streams.—The level of streams generally determines that of the ground water in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron River and Swan Creek were unusually low, and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. Huron River, being a longer stream, and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which is within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is most marked along its course rather than in any other part of the region.

Early winter of 1903.—This appears to have been an important factor in bringing on the present acute shortage. According to the official records, the permanent freezing of the ground took place on November 17, which was before heavy snows and heavy winter rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and early spring months. This

was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the ground water was at an unusually low stage.

Deficiency of rainfall in 1904.—The opening of the spring of 1904 with a low ground-water supply was followed month after month during the summer by a deficient rainfall, and the shortage consequently became very serious. This is brought out by the following table, which gives the precipitation by months of 1904. Detroit lies about 25 miles northeast of the area; Grape and Dundee about 10 and 20 miles southwest, respectively; Eloise less than 15 miles north, and Ypsilanti 20 miles northwest. The deficiency, it should be noted, has been restricted to spring and autumn months, and thus causes a dry year even though the annual precipitation is about up to the normal:

Rainfall, in inches, in the vicinity of the lower Huron River region.

Month.	Detroit.		Eloise.		Dundee.		Ypsilanti.		Grape.	
	1904.	Normal.	1904.	Normal.	1904.	Normal.	1904.	Normal.	1904.	Normal.
January	3.34	1.94	3.98	1.69	5.37	.....	4.54	1.90	4.17	1.44
February	2.55	2.33	.....	2.16	4.06	.....	2.98	2.46	2.62	1.80
March	4.09	2.29	.....	3.01	5.45	.....	4.92	2.45	3.16	2.32
April	1.65	2.24	1.01	1.32	2.36	2.41	1.66	2.24	2.04	2.24
May	2.36	3.51	1.19	3.27	3.06	2.88	2.58	4.09	2.71	3.61
June	1.08	3.69	.79	3.26	1.30	4.53	.56	4.25	1.49	3.57
July	2.94	3.36	2.52	4.16	2.84	4.06	3.03	3.33	2.96	2.63
August	3.20	2.71	3.69	1.95	4.73	3.52	3.92	2.14	4.31	2.52
September	4.23	2.47	3.83	2.61	4.30	2.64	6.21	2.86	4.67	2.36
October	.86	2.53	0	2.61	.82	2.11	1.09	2.64	.93	2.00
November	.19	2.69	0	2.38	.05	2.09	.09	3.23	.02	2.75
December	1.83	2.57	1.88	2.20	2.53	2.02	1.96	2.38	1.90	2.02
	28.32	32.33	.....	30.62	36.87	.....	33.54	33.97	30.98	29.26

CONCLUSIONS.

The low rainfall, which in the spring of 1904 varied from one-eighth to somewhat more than one-half of the usual amount at the stations in the tables, was, on the whole, even less in the lower Huron River region itself. The deficiency of rainfall, following as it did an autumn and winter during which little water was absorbed owing to the frozen condition of the ground, together with the preceding dry season of 1903, seems ample to explain much if not all of the observed shortage.

Although considerable rain fell in July, and even more than the normal in August, it came largely as short heavy showers, and the water, instead of soaking into the ground, as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell. In this connection it may be remarked that,

while the shortage was felt in the region under discussion sooner than elsewhere, the drought became severe enough later in the summer to be felt through all the States bordering the Ohio and eastward to New England, causing much shortage in wells.

If, as seems probable, the failure of the wells is due largely to the severe drought of 1903–4, the return to the normal rainfall should result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or perhaps a succession of wet years, occurs.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey material when dried out may, to a certain extent, crumble and become more or less clogged, so that their capacity for carrying water is lessened or destroyed even when the ground again becomes soaked. The return in any case will probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

The wells in the lower Huron River region obtain their supplies largely in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more open and jointed portion of the rock, because there is less resistance to its flow through the crevices and openings in the rock than through the compact clayey deposits which so generally overlie the rock formations of the region. The rock formations appear, therefore, to take in the water from the overlying glacial deposits, and, as shown above, a deepening of the wells into the rock has generally met with at least partial success. The great majority of wells now are exceptionally shallow compared with those of large areas in Michigan, where depths of 100 to 150 feet or more are common. It seems probable that wells of such depths in the region under discussion would yield permanent and abundant supplies.

WATER SUPPLIES OF WAYNE COUNTY.

By William Hittell Sherzer.

GENERAL STATEMENT.

The county of Wayne, with an area of 601.6 square miles, has according to the State census of 1904, a population of 386,827, or one person for each acre of ground. Outside the cities and incorporated villages the average is 61 to the square mile, or one to every 10 acres.

RAINFALL.

The following table, constructed from data supplied by the State weather service, shows the average monthly and annual precipitation in or near the county:

Precipitation, in inches, for Wayne County and for adjoining portions of Oakland, Washtenaw, and Monroe counties.

Station.	County.	Period of observation (years).	Monthly precipitation.					
			Jan.	Feb.	Mar.	Apr.	May.	June.
Detroit	Wayne	34-35	1.91	2.28	2.42	2.22	3.30	3.83
Grape	Monroe	17-18	1.59	1.82	2.32	2.24	3.56	3.45
Eloise	Wayne	7- 8	1.93	2.32	2.68	1.71	2.83	3.09
Birmingham	Oakland	14-18	1.71	1.89	2.16	2.46	3.14	3.10
Ypsilanti	Washtenaw	20-23	2.00	2.54	2.51	2.24	3.90	4.05
Dundee[a]	Monroe	5	2.25	2.30	2.71	2.40	2.91	3.89

Station.	Monthly precipitation.						Total years.	Average annual precipitation.	Annual precipitation corrected for epoch.[b]
	July.	Aug.	Sept.	Oct.	Nov.	Dec.			
Detroit	3.36	2.69	2.63	2.38	2.56	2.35	34	32.13	.....
Grape	2.65	2.69	2.50	1.94	2.60	2.01	17	29.43	30.72
Eloise	3.93	2.34	2.79	2.44	1.91	2.16	5	28.70	29.59
Birmingham	2.86	2.47	2.55	2.38	2.67	1.76	9	27.50	27.55
Ypsilanti	3.45	2.42	3.02	2.53	3.01	2.37	18	33.78	34.66
Dundee	3.81	3.77	2.97	1.85	1.68	2.41	4	33.83	33.83

[a] Private instruments, perhaps not in accord with Government instruments.

[b] The last column contains corrections for epoch made by averaging the Detroit annual records for each term of years represented by observations at other stations. The monthly averages have not been corrected for epoch. In the case of Ypsilanti the average annual precipitation for eighteen years was taken, since there are gaps in the record for the longer period on which the monthly averages are based.

The monthly averages are based on all the records available for each station, whether consecutive or not, and include March, 1905. It is unfortunate that they do not all cover equally long periods of time, for then the totals would be more strictly comparable. The distribution of the rainfall over the year is a matter of no little importance, since a frozen condition of the soil leads to the run-off of much water that would otherwise be absorbed and contributed to the underground supply. The average rainfall for the county is about 31 inches; over a belt extending across the middle, from Monroe northward into Oakland County, it is 10 to 15 per cent less, but it increases eastward to the Detroit River and still more rapidly to to the west. For the last seventeen years the records for a station in each belt are complete: Ypsilanti, 33.91 inches; Grape, 29.43 inches; Detroit, 30.78 inches. In all the years for which we have records at Eloise and Birmingham, located in the central belt, the precipitation is less than it is immediately to the east and to the west. It is interesting to observe that this central belt, with its

diminished precipitation, is in a sand-covered region, the covering having been produced in a way to be presently described, and it seems that the extra heat radiated from such a soil might readily reduce the amount of moisture precipitated over the region. A study of the above table shows that the reduction is most pronounced for the month of June, when we have maximum sun power combined with least protection of the soil by crops. This, however, is only a partial explanation, since the reduction in the precipitation for this belt extends over the entire year, when the question of soil must be largely eliminated. Prof. M. S. W. Jefferson has suggested that the series of high moraines extending in a northeast-southwest direction across Washtenaw and Oakland counties may cause the increase of precipitation in the western belt, while the descending and slightly warmed currents, having a prevailing easterly course, would part less readily with their moisture until the immediate effect of the Great Lakes was felt. In other words, we may have here some such effect as is produced by the "Chinook" winds of our Western States. The morainic belt stands from 800 to 1,100 feet above tide, while the drier belt east of it is only 650 to 660 feet above. Further observations upon rainfall, temperatures, and directions of storms in this and adjoining areas would throw light on the subject.

SURFACE WATERS.

RESERVOIRS.

From data obtained from Prof. M. E. Cooley, of the University of Michigan, State Geologist Lane has estimated that 38 per cent of the total precipitation may be collected from roofs and secured in cisterns,[a] and that with a rainfall of 32 inches, practically the same as that of Detroit, every 100 square feet of horizontal surface will yield 100 cubic feet of water annually, or about 25 barrels. This is but a little more than one-third of what actually falls on a roof of such area, the remainder being lost in wetting the roof, evaporation, blowing or sliding of snow, etc. Where limited quantities of practically pure water are required, as for laundry or domestic purposes, nurseries, and boilers, simple precautions would secure a much larger percentage. In addition to the dust, coal dirt, and organic matter derived from the collecting surface, this water contains similar matter taken from the air, and in addition appreciable amounts of ammonia, nitric and nitrous, sulphuric and sulphurous acids, carbon dioxide, and other gases of the atmosphere. There are large reservoirs in the brickyards to the west of Detroit, where excavations made into the old lake clays, to be presently mentioned, serve as

[a] Lane, A. C., Water resources of Lower Peninsula of Michigan: Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, p. 45.

ɔcting basins for the surface drainage and supply the necessary er for softening the stiff clays, the driven or bored wells at the kyards supplying merely drinking water. Throughout the ıty cisterns are used in dwellings, and in districts where wells are l to obtain they are connected with barns for use of stock.

LAKES.

ocation.—In striking contrast with its neighbors, Oakland to north and Washtenaw to the west, Wayne County is surpris- y deficient in lakes or permanent ponds. Aside from the small ous on the river flats, the only natural lakelet lies 1 mile east of thville (sec. 2, Northville Township), and is known locally as kes Lake. It has a maximum diameter of about 1,000 feet, is drained by a small stream into the middle branch of River ıge. Occupying a depression between the morainic knolls of region, it receives considerable surface drainage, and is said also ɔe fed by springs and to be well stocked with fish. Owing to its ıt elevation above the village of Northville, it has not been ized for water supply. Although so poorly supplied with inland ɔs, Wayne County touches Lake St. Clair on the north and ɔnds to Lake Erie on the south.

he water of Lake St. Clair is utilized to a greater or less extent the residents of Grossepoint Township. Many of those who ɔin the lake pump the water direct by means of windmills and ribute it over their grounds from elevated storage tanks. Drink- water is ordinarily procured from wells, to be described later.

Vaterworks.—The village of Grossepoint Farms is supplied with er drawn from the lake at a point about 1¾ miles from the shore, ı great distance being necessitated by the shallowness of the lake. ɔ plant was installed in 1890 by the Grossepoint Construction ıpany and is operated in connection with an electric-light plant. ɔ original cost was $65,000. The water flows by gravity into a ling basin, from which it is pumped direct. Two Walker pumps used, with a daily capacity of 5,750,000 gallons. The ordinary ssure is 35 pounds to the square inch and the fire pressure is 90 ınds. In 1897 there were 4 miles of mains, 110 taps, and 27 ɔlic hydrants. During the year 1904 the pumpage was 76,600,140, ı daily average of 209,290 gallons. There is a resident population ɔnly 615; but this large daily average does not mean a daily per ita consumption of 340 gallons, for the excessive amount is due ɔart to the large number of summer transients.

STREAMS.

DETROIT RIVER.

General statement.—The water supply of about seven-eighths (the entire population of Wayne County is derived from Detro River, naturally one of the most magnificent streams of potabl water in the world, when volume, purity, temperature, and constan are considered. Opposite the center of the city of Detroit its breadt is 2,200 feet, its average depth is 37 to 38 feet, and there is mai tained a rather constant velocity of 2 miles an hour. With the lev of Lake Erie at normal, it is calculated by the United States engine that there flows by Fort Wayne in the southern part of the city ea second 209,900 cubic feet. In the American channel the maximu velocity is 2½ miles an hour, and the average somewhat less than miles. During July and August, 1897, detailed measurements the flow were made by Clarence W. Hubbell, engineer of the Detr waterworks. Float methods gave an average flow of 65,000 cu feet a second and current meters one of 53,000 cubic feet for t channel. When the channel is covered with ice and the Canad channel is open the flow is reduced to 36,000 cubic feet a seco The temperature of the water ranges from 32° to 70° F., and greatest vertical range between the top and bottom has never b observed to exceed one-half degree. Between shore and midstre the temperature of the water may vary as much as 8° or 9°, this fact may be used to detect possible contamination from tribut streams.

Lake St. Clair, which extends nearly to Detroit, has served many years as a great settling basin, as is shown by its shallow (dition and the growing delta at its head. The turbidity of the r water is low except after storms, when the bottom of Lake St. C may be more or less disturbed and the small tributary streams b in sediment. The following is the latest available mineral anal of the river water:

Mineral analysis of Detroit River water.[a]

	Parts per million.		Par mil
Calcium (Ca)	24.61	Sulphate radicle (SO_4)	
Magnesium (Mg)	7.44	Chlorine (Cl)	
Aluminum (Al)	1.80	Silica (SiO_2)	
Iron (Fe)	Trace.		
Sodium (Na)	2.76	Total	9
Potassium (K)	Trace.	Total mineral matter	10
Carbonate radicle (CO_3)	50.85	Organic and volatile matter	3

[a] Twenty-first Ann. Rept. Michigan Board of Health, 1902, p. 63. Expressed by analyst in thetical combinations; recomputed to ionic form at United States Geological Survey. For mineral analyses see Lane, A. C., Lower Michigan mineral waters: Water-Sup. and Irr. Paper N U. S. Geol. Survey, 1899, pp. 18-19.

Waterworks.—The city of Detroit, with a population of 317,591 [a] and an area of approximately 29 square miles, is supplied with Detroit River water from a single pumping station, believed to be the largest in the world. The reservoir formerly used has been given up and the pumping is direct, through two distinct systems, an upper and a lower. The central station is located in the extreme eastern part of the city, opposite Belle Isle, and the water is taken from the American channel through three boiler-plate intake pipes, 5 and 6 feet in diameter, provided with box strainers placed in 28 feet of water.[b] These intakes are 1,030 feet, 1,505 feet, and 1,505 feet in length, respectively, and reach out from the west shore into the channel 500 feet and 1,000 feet. Through these pipes the water flows by gravity into a settling basin 365 by 775 by 16 feet deep. Straining wells are interposed between this basin and the pumping wells.

In order to secure water from nearer the center of the main channel there has been constructed a 10-foot tunnel 3,160 feet long, lined with 1.5 feet of vitrified brick and terminating in a substantial stone crib located about 800 feet above the head of Belle Isle. This tunnel has above it about 36 feet of stiff blue clay and about 30 feet of water. Connecting with this river tunnel is a shore tunnel, lined with common brick and leading to the receiving basin or direct to the pumps.

The pumps used are six in number: One 30,000,000 comp. beam, two 24,000,000 comp. beam, one 24,000,000 triple Allis, two 25,000,000 triple Allis-Chalmers; total daily capacity, 152,000,000 gallons. For the year 1904 the average daily consumption was 59,385,121 gallons, or 183 gallons per capita. The average cost of pumping is $3.37 per million gallons. The total length of mains is 644 miles, of which 559 belong to the city proper and 85 to the suburbs, being paid for by the villages supplied. The total number of fire hydrants is 4,100, and of service taps in the city 63,656. The total estimated cost of the plant is $7,344,456. The income for 1904 for metered water was $155,266 and for unmetered water $277,126.

The suburban villages supplied are Hamtramck (population 1,559), Highland Park (612), Woodmere (5,034), River Rouge (2,474), and Delray (6,627). These villages present a combined population of 16,306, of which it is estimated that 12,926 are supplied with water through 2,570 taps. The water is all metered and double city rates are charged.

With the system of direct pressure it has been found impracticable to force the water to all parts of the city, portions of which are 60 to 70 feet above the river, or to the upper floors of the taller buildings. Accordingly in 1898 a double system was installed, each with its own

[a] State census, 1904.

[b] An interesting article by Clarence W. Hubbell on the Detroit waterworks is to be found in the Engineering Record, vol. 47, No. 25, 1903, p. 650.

set of pumps and mains, one operated under low and the other under high pressure. Frequent tests at various points in the two systems show a mean pressure in the lower of 17.4 to 51.8 pounds per square inch, and in the upper of 26.6 to 60 pounds per square inch. Buildings more than five stories high are provided with their own private pumps.

Below the city of Detroit the people along the river front, owing to the nature of the ground water and the poor drainage, are dependent on Detroit River. The villages of Ford and Trenton and the city of Wyandotte are supplied by pumping plants drawing water from near the west bank. On Grosse Isle water is pumped by windmills directly from the river into elevated tanks and used for stock and lawns and for domestic supplies, although good well water is also procurable. Wyandotte and Trenton own their own waterworks systems, operating them in connection with electric-light plants.

Ford is supplied with water by the Michigan Alkali Company, whose plant was installed in 1893. The village (population 1,372) laid 5 miles of mains at a cost of $18,500, the company having 1 mile. The water is drawn from within the harbor line and pumped direct by five pumps—one Holly of 5,000,000 gallons capacity, two Snow of 6,000,000 each, and two Nordling of 3,000,000 each, giving a total daily capacity of 23,000,000 gallons. The average daily pumpage is 17,000,000 gallons, large quantities being used for manufacturing purposes. The village possesses 40 hydrants and 163 service taps. No meters are in use, the ordinary dwelling paying a flat rate of $4 per annum. The village is without sewers.

Immediately to the south of Ford, and adjoining it, is located the city of Wyandotte, with a population of 5,425. The water plant was built by the city in 1889–90 at an original cost of $61,371. The intake pipe reaches out 150 feet beyond the harbor line and the pumping is direct, with a Hughes pump of 1,500,000 gallons capacity and a Laidlaw-Dunn-Gordon of the same capacity, making a total daily capacity of 3,000,000 gallons. The average daily consumption is 500,000 gallons, which, based on the entire population, represents a per capita consumption of about 92 gallons. It is estimated that about 90 per cent of the people are actually using this water, the remainder depending on shallow wells. There are 120 public hydrants, 1,300 service taps, and 11 miles of mains. The ordinary pressure is 45 pounds and the fire pressure 80 pounds. Only a small amount of water is metered and this to the few larger consumers. Lying so nearly at a level with the river itself the drainage is poor, while the prevailing sandy soil acts as a sponge and retains much impurity. The city is sadly in need of the best system of sewers that can be procured. Money has already been appropriated for building these, and it is unfortunate that sufficient unanimity of opinion can not be secured to push the work to completion.

Four miles south of Wyandotte lies the village of Trenton, located on higher ground and with a clay soil. The village, with a population of 1,201, installed its own plant in 1896 at a cost of $11,300. The intake pipe reaches out 210 feet into the American channel, between the mainland and Grosse Isle. A Worthington pump of 300,000 gallons capacity is used, with a second high-pressure pump of 750,000 gallons capacity. There are 22 hydrants, and in 1897 there were 160 taps and 4 miles of mains. The ordinary pressure is [illegible] pounds, and the fire pressure 100 pounds. The annual cost of operating is estimated at $1,700. It is further estimated that 85 per cent of the population use the river water. The average daily pumpage is 130,600 gallons, or 109 gallons per capita for the entire village. No sewers have yet been projected.

Contamination.—Although naturally of excellent quality, Detroit water is not above suspicion and safety lies only in constant vigilance. Not far from 400,000 people dwell in the St. Clair drainage basin between Detroit and Lake Huron. Connors Creek, just above the city, drains a region of cemeteries and truck farms, rich in compost, and in the early spring is a menace to Detroit. The melting snows and heavy rains have swept the accumulations of the winter into the river five-eighths of a mile above the present city intakes and on the same side of the river. This condition of affairs will be remedied by the new tunnel. The city board of health conducts monthly sanitary analyses, but these should be more frequent, especially during the spring, summer, and fall. The following table is taken from its 1902 report, and is of especial interest, as it shows the variations in the character of the water through an entire year:

Sanitary analyses of Detroit River water, July, 1901, to June, 1902.

	July.	August.	September.	October.	November.	December.
Appearance [a]	C.	C.	C.	C.	C.	C.
Total solids.....parts per million..	108.4	104.2	103	111	104	111
Volatile matter.....do....	41.4	36.4	44.4	41.8	34.8	41.6
Nonvolatile matter.....do....	67	67.8	58.6	69.2	69.2	69.4
Free ammonia.....do....	.008	.006	.020	.016	.024	.012
Albuminoid ammonia.....do....	.074	.080	.126	.116	.092	.102
Nitrogen as nitrates.....do....	.115	.082	.164	.210	.099	.198
Nitrogen as nitrites.....do....	0	0	0	0	0	0
Chlorine.....do....	2.80	2.90	2.60	2.80	2.70	3.15
Oxygen absorbed in 15 minutes...do....	.40	.32	.44	.48	.44	.48
Oxygen absorbed in 4 hours.....do....	.76	.72	.88	.96	.84	.72
Bacteria per cubic centimeter.....	98	106	37	37	103	104
	43	84	98	104	170	199
	116	192	160	82	89	265
	62	47	52	206	204	99
Growth in 2 per cent carbolic-acid gelatin	None.	None.	None.	None.	None.	None.

[a] C=clear; N. C.=nearly clear; S. T.=slightly turbid.

Sanitary analyses of Detroit River water, July, 1901, to June, 1902—Continued.

	January.	February.	March.	April.	May.	June.
Appearance [a]	C.	N. C.	N. C.	S. T.	S. T.	N. C.
Total solids.....parts per million..	105.2	115	116.4	116	118.2	112
Volatile matter.....do....	39.6	39	36.8	39	40	[illegible]
Nonvolatile matter.....do....	66.6	76	79.6	77	78.2	[illegible]
Free ammonia.....do....	.026	.028	.024	.016	.022	[illegible]
Albuminoid ammonia.....do....	.082	.086	.092	.086	.082	[illegible]
Nitrogen as nitrates.....do....	.230	.148	.115	.164	.198	[illegible]
Nitrogen as nitrites.....do....	0	0	0	0	0	[illegible]
Chlorine.....do....	2.70	3.15	2.50	2.75	3.10	[illegible]
Oxygen absorbed in 15 minutes...do....	.40	.36	.44	.40	.32	[illegible]
Oxygen absorbed in 4 hours.....do....	.76	.84	.88	.80	.84	[illegible]
Bacteria per cubic centimeter.....	87 132 26 204	124 353 197 402	170 135 266 333	105 190 235 302	31 48 66 115	[illegible]
Growth in 2 per cent carbolic-acid gelatin	None.	None.	None.	None.	None.	None.

[a] C.=clear; N. C.=nearly clear; S. T.=slightly turbid.

Since the first crude pumping plant was installed, in 1825, with its horse-driven pumps and tamarack mains, the city of Detroit has repeatedly suffered from epidemics of disease, the germs of which, without reasonable doubt, came from the river water. In 1832, at the time of the Black Hawk war, a boat load of soldiers on their way to Chicago, with cholera aboard, anchored at the head of Belle Isle, and very soon the disease was epidemic in the village of Detroit, 96 citizens succumbing. Two years later cholera again appeared and 7 per cent of the population died in one month. Similar outbreaks occurred in 1849 and in 1854, causing 35 to 40 deaths daily.

Danger from cholera to-day is remote, but that from typhoid is constantly at hand. The average number of deaths in Detroit from this disease from 1886 to 1904, inclusive, being 72, ranging from 39 to 209. The maximum was reached in 1892, following the dredging of the delta of Black River, at Port Huron, by the United States Government.[a] This delta contains sewage deposits from the city of Port Huron, and its disturbance appears to have contaminated St. Clair and Detroit rivers. Although some dredging had been done previously, the dredges were especially active in the river in 1892, the excavated material being loaded on barges and dumped in St. Clair River below Port Huron. Gardner S. Williams, at the time civil engineer to the Detroit water board, has estimated that it would require about ten days for this material to reach Detroit. Allowing twelve days for the incubation stage and twenty-six days to produce death, this gives a total of forty-eight days. The dredging began on April 16, and on June 5 4 deaths from typhoid were recorded in Detroit; in the next twenty-five days 38 deaths were reported from this disease. Since the dredging was completed the typhoid rate dropped back to what appears to be the normal. From July 1, 1903 to July 1, 1904, 64 deaths were reported, or 2 deaths for each

[a] Williams, G. S., Typhoid fever and the water supply of Detroit: Proc. Sanitary Convention, Detroit 1897, p. 90.

),000 of population. This is low when compared with many other ties, and it is possible that some of the cases were contracted elsehere; still, the great city of Detroit should not rest satisfied until has the lowest attainable rate. The mortality rate for this disease is ven by Dr. V. C. Vaughan as 7.5 per cent, so that 64 deaths during ıe last year would indicate that there had been about 850 cases, and nce only about one person in from 3 to 10 actually contracts the sease on exposure, we may assume that 2,500 to 8,500 people are ınually exposed to this lingering and expensive disease; say one in ery ten families. As pointed out by Professor Williams, nothing ıt the expense stands in the way of a filtering plant that would oviate such danger, and until this is secured it is on the side of safety filter or boil the water in the home.

If there is reason to view the water secured from the head of Belle sle with some suspicion, there are still better grounds for viewing ith positive distrust that which has received the full contamination f the city of Detroit and the Canadian towns across the river. Since ractically all the water that is pumped finds its way sooner or later nto the river again as sewage or surface drainage, this means that 0,000,000 gallons in this condition are daily returned to the river. The Canadian towns opposite Detroit (Walkerville, Windsor, and Sandwich) have a combined population of about 18,000, and contribıte to the river daily about 5,800,000 gallons of polluted water. If ve assume that within the limits of Detroit 50 per cent of the rainfall inds its way to the river after having taken up the filth of the roofs, streets, gutters, and walks, we have on an average 22,000,000 gallons laily from this source. The total, to say nothing of the pollution eceived below the city of Detroit, is 76,000,000 gallons daily of sewıge, slops, and street washings. This represents 11.7 cubic feet a econd, or 1 gallon for every 1,800 gallons that flow by the fort in the outh part of the city, where gaging was made. This assumes that he two are uniformly mingled. Since, however, Ford, Wyandotte, ınd Trenton are on the same side of the river as Detroit and the conours of the river banks are such as to crowd the shore currents to the rest, the case is certainly more serious even than the above figures ndicate. Then, too, it must be remembered that it is really a quesion of the quality of the contaminating material rather than the uantity, and that there are in Detroit on the average nearly 1,000 ases of typhoid each year. As a direct line by river from Woodard avenue to the Wyandotte intake is 10½ miles and the average elocity is somewhat less than 2 miles, the outflow from Detroit sews may be pumped to unsuspecting victims at Wyandotte in from x to eight hours after its discharge into the river. This does not ve time for the process of oxidation to complete its work of purifition, nor to secure the death of the organisms causing disease. In

the case of Ford, lying between Wyandotte and the source of pollution the condition would be still more unfavorable, while with Trenton, there is the additional contamination from Wyandotte, which will be still more serious with the direct flow from the sewers when these are finished. The following sanitary analyses of the water from the river at Wyandotte, together with one of water from a well for comparison, are supplied by Dr. V. C. Vaughan:

Sanitary analyses of Wyandotte waters.

[Parts per million.]

	1.	2.	3.	4.	5.
Total residue	179	173	187	221	1,[illegible]
Inorganic matter	112	101	106	191	[illegible]
Organic matter	67	72	81	30	[illegible]
Earthy bases, as oxides				10.976	[illegible]
Chlorine	25.45	6	25.57	27.57	[illegible]
Sodium	20.75	3.90	16.63	14.67	[illegible]
Sulphate radicle (SO_4)				None.	Strong trace.
Free ammonia	.024	.0106	.008	.08	[illegible]
Albuminoid ammonia	.032	.016	.016	.52	[illegible]
Nitrogen as nitrates				.15	[illegible]
Nitrogen as nitrites				.003	[illegible]
Bacteria developed in 72 hours	38	82	45	1,890	2,[illegible]
Color	Slightly opal.	Opalescent.	Opalescent.	Clear	Sedimentary.
Hardness	120	114.29	114.29	100	[illegible]

Nos. 1-3, river, 1898; 4, river, 1890; 5, well, 1890.

Nos. 1 and 2 were pronounced safe by Doctor Vaughan, while the other three caused death of rabbits and guinea pigs and were pronounced unsafe. The last two analyses were made at the time of a typhoid epidemic, which was believed to have been caused by milk contaminated from the well. Until something can be done the residents of these places should both filter and boil their drinking water. In the way of securing a better supply of water several propositions may be considered: (1) Installing a filtering plant; (2) extending the Detroit mains from River Rouge to Trenton; (3) using the Swan well, case the water from that well proves potable and not too hard (see analysis p. 44); (4) putting down wells into the Sylvania sandstone.

SMALLER STREAMS.

General statement.—Named in order from the north, the main streams crossing the county are Connors Creek, River Rouge with its three branches, Ecorse River, Monguagon Creek, Hale Creek, and Huron River. Owing to the comparatively narrow drainage basin and the very direct slope of the land these streams attain no considerable size in southeastern Michigan.

The highest and roughest land in Wayne County is found about the northwest corner, where the greater parts of Northville and Plymouth townships are covered with morainic knolls and ridges, the extreme northwest corner of the county attaining an altitude of 97 feet above sea level. The average surface slope from there southeastward to Detroit River is 16 feet to the mile. East of the morainic area the surface is remarkably flat and even, with an average slope of 8.7 feet to the mile, not enough to be detected by the eye alone. The cutting of their beds, especially in their upper course has considerably reduced the average fall of the streams, but the

loose condition of the materials over which they flow is sufficient to keep them supplied with more or less sediment and unfitted for general use. In only one or two instances do the streams touch bed rock, and then only for very short distances.

Farmers whose places adjoin these natural watercourses use this supply for their stock, for irrigation of their truck farms, etc. At Dearborn the Arna mills use the water of River Rouge, after settling, in their dyeing business. At the former Dearborn power house of the Detroit, Ypsilanti, Ann Arbor, and Jackson Electric Railway the Rouge supplied water for the boilers.

Waterworks.—The Wayne County Infirmary, at Eloise, has its own system of waterworks, the plant having been installed in 1902. Previous to that date the water was pumped from the lower branch of River Rouge, but it is now taken from a large well on the flats of the middle branch near Perrinsville. This well, which is 35 feet in diameter and 18 feet deep, receives the flow from the river as well as some surface water, necessitating a plant at Eloise. The water is pumped by a Worden & Hughes pump having a daily capacity of 1,152,000 gallons and driven with a 40-horsepower engine. The water is conveyed through 3¾ miles of 8-inch cast-iron tubing, buried to a depth of 5 feet, and emptied into an artificial lake, which is also partly filled by surface drainage. From this reservoir it is again elevated by pump and filtered through four steel tanks, 6 feet in diameter by 9 feet in height, filled with crushed quartz. The daily capacity of the filters is 200,000 gallons. There are 19 hydrants on the grounds. The cost of the plant was $30,000 and the annual cost of operating is $1,800. This water is not used for drinking and cooking purposes, the inmates being supplied from springs (see pp. 63-64). The number of inmates cared for in 1904 (year closing September 30) was 1,088, with about 100 employees. River Rouge water is used mainly for the boilers, on the grounds, and for flushing the sewers. The following analysis of this water from the middle branch was made by L. M. Gelston, assistant in the hygienic laboratory of the University of Michigan. It is considerably harder than that of the lower branch, owing undoubtedly to the fact that the middle branch receives the flow from so many springs, especially those from the glacial deposits.

Analysis of water from Middle Branch River Rouge.

	Parts per million.		Parts per million.
Inorganic matter	732	Free ammonia	0.133
Organic matter	96	Albuminoid ammonia	.124
Chlorine	37	Total residue by evaporation	828
Potassium	1.5		

Reaction neutral. Algæ, protozoa, and bacteria present.

Contamination.—In a suit brought against the infirmary in 1896 for the pollution of the stream the following analyses were made by Prof. J. E. Clark, M. D., of the Detroit College of Medicine. It was then legally decided that the Rouge was being seriously contaminated, and the infirmary was required to put in settling basins for its sewage. A series of such basins now in use treat the sewage with alum and lime and then run it through gravel.

Analyses of water from River Rouge, showing contamination.

[Parts per million.]

	Above sewer.	From sewer.	250 to 300 feet below sewer.
Mineral matter	280	740	750
Organic matter	150	380	370
Chlorine	5	105	95
Free ammonia	.302	48.8	1.93
Albuminoid ammonia	.366	32.58	1.44
Total solids	430	1,120	1,000
Bacteria	10,900	325,000	12,300

The table is of interest because it shows the ordinary condition of the water in this stream, and in addition those substances derived from sewage which suggest the presence of dangerous bacteria. The amount of chlorine, combined to form common salt, has been increased 19 times, while the ammonia has not risen in proportion to the amount actually present in the sewage itself. A complete analysis of the water would have shown that much of this had been oxidized into nitrites and nitrates, which along with the chlorine furnish an index to the probable amount of sewage contamination. The percentage of bacteria added to the stream is small and to but a slight extent capable of producing disease, but there is a likelihood that sooner or later those of a more serious nature will have to be reckoned with.

Huron River, the largest stream of the county, receives before entering the county the sewage and drainage from Ann Arbor and Ypsilanti, with a combined population of 22,200 people, and is still more seriously polluted by the sanitary works at French Landing. None of the villages in Wayne County, however, draw on the river for a public supply.

GROUND WATERS.

WATERS FROM LACUSTRINE AND RIVER DEPOSITS.

FORMATION OF DEPOSITS.

A series of old shore lines and beaches, made by the predecessors of the present system of Great Lakes, traverse Wayne County in a general northeast-southwest direction. In some places these are closely placed, and a single township may have as many as six; in

other places they are broad and rather widely separated. Through the work of the United States and Michigan geological surveys these ancient beaches are being carefully followed and maps showing their location will soon be available. The waves of the lakes, as they stood at successive levels, threw up broad, rounded ridges of sand, or sand and gravel, attaining a maximum thickness of 25 to 30 feet and consisting of cross-bedded deposits resting upon the underlying clay.

Where sand was especially abundant it was seized by the lake winds and heaped into mounds and ridges (dunes) and sometimes carried landward for a considerable distance, being there spread out into a relatively thin, unstratified sheet. A broad belt of such deposit, the joint work of wind and wave, extends across Sumpter, Romulus, Nankin, and Livonia townships, reaching over into those adjoining. A similar belt, but with less breadth, passes across Huron, Taylor, Dearborn, and Redford; and a third, less continuous, passes through Brownstown, Ecorce, Springwells, Detroit, and Hamtramck.

At the several levels of the old system of lakes, Huron and Rouge rivers formed delta deposits opposite their mouths, spreading sheets of stratified sand and gravel over a considerable area. This was particularly true during the stage known as Lake Arkona, when the Huron covered from 30 to 35 square miles of Van Buren and Sumpter townships with such a dressing, extending eastward as far as French Landing and attaining a maximum thickness of over 20 feet. A similar but less extensive formation was laid down where the middle branch of the Rouge discharged into Lake Arkona east of Plymouth, covering the eastern part of Plymouth Township, western Livonia, northeastern Canton, and northwestern Nankin. These delta deposits are continued up the stream valleys, where they form terraces of stratified sand and gravel, the former flood plains of the Huron and Rouge.

WATER SUPPLY.

These loose, unconsolidated deposits, mantling the clay, are very porous and readily absorb a large part of the rainfall. They are at the same time very permeable and deliver this water readily. For a precipitation of 32 inches, with a surface run-off and seepage flow of 25 per cent, there would be an average daily addition of 132,210 cubic feet over every square mile, or nearly 1,000,000 gallons. The water sinks to the underlying clay and is there held, or works its way slowly by underground passages and seepage down a gentle slope. This brings it quite near the surface, though, owing to the way in which it is held, it possesses no head. Only shallow wells, ranging from 5 to 25 feet, are required to tap this supply; a very common depth is 10 to 15 feet. In sinking these it is usually not necessary to reach the clay, but when the supply is reduced it is

frequently desirable to make an excavation into the clay, which wi serve as a reservoir. These wells as a rule are dug, but are some times driven, and are cased with barrels, planks, brick, stone, o crocks. The water is obtained usually by suction or chain pump the windmill being occasionally used. In the case of wells in sa the bucket, with chain, rope, or pole, is used for dipping, the old fashioned "sweep" being still occasionally found. While the supply is ordinarily sufficient and very frequently abundant, it fluctuates with the amount of precipitation, and after prolonged drought may disappear or be so lowered as to require deepening of the wells. How much any particular well will be affected, and how promptly, will be determined by the extent and thickness of the deposit supplying the water.

In one-third of the wells from which data were secured the owner report the water to be soft and suitable for laundry use, so that no cisterns are required. This shows that there has been but littl calcium or magnesium carbonate dissolved from the sand, gravel, o clay, either because these substances were not present originally o have been leached out, or because the water has not had time to g them in solution. In two-thirds of the wells, particularly in tho which approach or reach the clay, the water was pronounced har In a few cases the water was reported to have changed from soft hard and vice versa. Other mineral ingredients, so common in oth types of wells, are absent here or only very sparingly present. T temperature of the water in these wells fluctuates more than in t deeper wells, being more affected by the surface temperature the air and soil. From what is known of other wells we m assert that the temperature will be highest in midfall and lowest midspring.

Although obtained with so little difficulty and expense, this wa is especially liable to contamination from house and barn drains and privies. Dupuit's experiments in France have shown that t area drained by a well is in the form of an inverted cone, the rad of the base of which may range from 15 to 160 times the depth the surface of the water in the well. This means that if it is 10 f from the surface of the ground to the level of the water in the w this well may receive drainage from buildings 150 to 1,600 feet d tant from the well. It has also been found by experiment that shallow well heavily pumped will drain a larger area than a de well subjected to moderate pumping. Although sand and gra may serve as filters for the removal of solid substances, subterrane channels are liable to be opened in time and direct pollution occ The sudden opening of such channels may explain why some we wholesome up to a certain time, become suddenly a source of gr

danger. This is probably what happened to the Millspaugh well at Wyandotte, the analysis of which is given in the table (p. 58). It is a mistake to suppose that the direction of the surface slope completely controls the direction of underground drainage. Wells of the type here discussed should be placed as far as possible from sources of infection and should be tightly cased with solid pipe or sealed crocks extending above the general level of the ground sufficiently to prevent any surface water from entering.

Around the margins of the sand dunes, where the superficial beds of sand and gravel thin out, exposing the clay, or where these beds are cut by surface streams through the clay, the water seeps out and gives rise to one type of springs. The flow may be slight and simply moisten the surface or it may be concentrated into a single flow of some volume. Most of these springs are found along the banks of Rouge and Huron rivers where they have cut across the old lake beaches or the deltas of their own formation. In Van Buren Township some of the farmers adjoining the Huron and its tributaries are utilizing the strongest of these flows, elevating the water to tanks by means of hydraulic rams. These waters show only small quantities of salt, gypsum, and calcium carbonate, with some iron. The largest spring supplied from this class is located on the place of G. E. Barlow, sec. 29, Livonia Township, just north of the middle branch of the Rouge, where it has been flowing strongly for many years. It now discharges through a 2.5-inch tube with considerable force—a hard water which contains calcium carbonate and calcium sulphate, but gives no reaction for salt. This is of significance, since it might prove to be of superior quality in the manufacture of beet sugar. If this spring were fully developed, along with others on the neighboring bank, the supply might prove sufficient for the village of Wayne, to which it could be carried by 7 miles of pipe. The fall is about 14 feet, enough to give the water a flow by gravity, but not enough to secure pressure. Wayne has made an unsuccessful attempt to secure a public supply by means of deep wells and had a survey made looking toward the extension of the Detroit city mains to the village. The expense of the latter plan was prohibitive for the time.

At the county infirmary at Eloise some 1,100 people are supplied with drinking water from a sand dune about one-half mile to the south, the water being collected into small reservoirs, from which it flows by gravity through 3-inch tiling and is distributed by pipes to the basements of the buildings and by hand to the drinking tanks on the upper floors. The effect is said to be somewhat constipating, but the water is pure and abundant. It is said to be soft, but does

not make a free lather. The following analysis of this water was made in April, 1888, by Dr. Samuel P. Duffield, of Detroit:

Analysis of drinking water at Wayne County Infirmary, Eloise.[a]

	Parts per million.		Parts per million.
Calcium (Ca)	587.48	Sodium (Na)	172.88
Carbonate radicle (CO_3)	181.66	Total	2,472.75
Magnesium (Mg)	54.83	Free carbon dioxide	2,914.28
Sulphate radicle (SO_4)	1,050.67		
Chlorine (Cl)	425.25		

WATERS FROM GLACIAL DEPOSITS.

FORMATION OF DEPOSITS.

The great Canadian ice sheets, which made at least two advances across this section of the State from northeast to southwest, reduced much hard rock to fine fragments and spread it over the bed rock in a sheet varying in thickness from a few to more than 200 feet. This deposit, consisting of tough unstratified clay, generally of a blue color and containing subangular fragments of bruised rocks, is technically known as "till." Stony portions of it, probably largely of an early ice invasion, have become compacted, and are popularly known as "hardpan." While this great ice mill was at work reducing the rock to powder streams of water beneath the ice, resulting from surface melting and rains, were assorting the deposits into gravel, sand, and clay. The pebbles, rounded by mutual grinding, and the sand were arranged in layers in certain places favorable for deposition, to be covered by beds of later-formed till. In this way was built up the so-called "ground moraine" of these great ice sheets. Much of the finest sediment seized by the subglacial streams was capable of being held a longer time in suspension and so was carried forward into the quiet bodies of water into which these streams drained, forming either deltas at the border or, where spread over the bottom, beds of finely stratified clay, quite different from the till itself. Beds of similar nature were formed in the ancient lakes, previously referred to, by the action of the waves on the till, the pebbles and sand during times of storm being tossed upon the beach, while the clay was carried into deeper and quieter water. Although nearly the entire county was covered by these waters, the only extensive deposits of these lake clays are found to the north and west of Detroit, where they are extensively used in the manufacture of brick. The result of this wave action was to cut down elevations left by the preceding ice sheet and fill in depressions, giving the entire region a more subdued aspect and more gentle slopes.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

WATER SUPPLY.

Character of beds.—The beds of ancient lake clays, as well as the till itself, are practically impervious and impermeable, and hence can yield no water supply. Water is to be obtained only from the interbedded sheets of sand and gravel, the occurrence of which, owing to their method of formation, is very irregular and uncertain. This makes the securing of a suitable water supply over these areas difficult, uncertain, and expensive. Especially is this true in the northeastern part of Van Buren, the northwestern part of Romulus, and certain parts of Dearborn townships. The rain water finds its way into these permeable beds, often in regions remote from the place at which they are tapped and frequently at a considerably higher level than the bottom of the well. Hence the water enters the well under pressure which may cause it to rise nearly to the surface or to overflow. As the water generally comes from a greater distance and from a greater depth than that of the type of wells previously discussed, its temperature is more uniform and the supply is more abundant and more constant. In general, also, the water is more highly mineralized, owing to its better opportunities for taking the minerals it encounters in solution. Of all those wells from which data were secured, 22.4 per cent were reported by the owners as soft and 77.6 per cent as hard. Where the water is drawn from just above the bed rock it is sometimes highly charged with minerals, such as salt, sulphur, iron, etc., which characterize the waters from the rock itself, and the inference is that the rock water has mingled with that from the glacial deposits.

Nonflowing wells.—The nonflowing wells generally vary in depth from 18 or 20 feet to 100 feet or more, 60 to 75 feet being a common depth. The shallower ones are dug and lined with stone or brick; the deeper ones are driven, bored, or drilled. In some instances no casing at all is used, the clay being firm enough to maintain the necessary opening to the water-bearing stratum. Owing to the considerable depth, heavy suction pumps are generally required and windmills are in common use. The deepest wells of this type are located in the northeastern part of Van Buren, northern Canton, northern Hamtramck, and southwestern Grossepoint townships, the maximum found having a depth of 182 feet. Owing to the nearness of bed rock to the surface in Monguagon and Brownstown townships, the wells of this class are necessarily shallow, many of them stopping just short of the rock in a bed of gravel. The height to which water will rise, with reference to the surface of the ground, depends on the head and the elevation of the ground at the mouth of the well, and each of these factors grows less toward the southeast. In the belts immediately surrounding the areas of flowing

wells, to be next described, the water comes very near or quite to the surface and drops back from it as we pass to the east or the west. In the wells of this class from which data were secured 80 per cent were reported hard and 20 per cent soft. When tightly cased to a level above ground the wells are safe from contamination. If the casing is too short at the top, or if no casing at all is used, they may receive surface drainage and become a source of danger. The collecting areas of this water appear to lie in the high morainic regions to the west and north, as shown from the general diminution of head toward the south and east. In a strip of territory extending northeastward from southern Canton and northeastern Van Buren townships many of the deeper wells give much salt, which presumably is received from the underlying bed rock. A few data are here given concerning three of the most striking. It is likely that the Barker wells penetrated the Antrim shale without the driller knowing he had entered bed rock.

The well of C. F. Bevernitz, NW. ¼ sec. 12, Nankin Township, is 60 to 70 feet deep, the Antrim shale lying at a depth of 70 to 80 feet. The elevation of the mouth is approximately 635 feet. The supply is good, but there is too much salt in the water to permit its use; a tobacco pail full is said to have yielded, on evaporation, a pint of salt. There has been some gas in the well. The water lacks only 4 feet of reaching the surface, its actual elevation being about 631 feet.

Edward Barker, NE. ¼ sec. 27, Canton Township, has two wells, which were sunk to a depth of 108 feet in 1901. The Antrim shale is supposed to be from 100 to 110 feet from the surface. The approximate elevation of the mouth of the well is 657 feet and the head is 12 feet, giving the water an elevation of 645 feet. Salt water was secured from near the bottom, 6 to 7 quarts yielding a teacup of salt. This water has been used for preserving pork. The well was plugged below to shut off this supply and fresh water was used from a higher level in the well.

W. A. Wallace, SE. ¼ sec. 32, Canton Township, has a bored well 70 feet deep. The Antrim shale lies at 80 to 90 feet. The elevation of the well mouth is 695 feet and of the water surface 687 feet. The water is secured from just over hardpan and is hard and salty, too much so to drink, but may be used for other household purposes. Cattle will drink it, and require no other salt.

Some of these mineralized waters not so highly charged with salt are being put on the market for their medicinal properties and sold in Detroit by the gallon. One of these sources of supply is on the Rouge flats at Plymouth. It is owned by Dr. M. V. B. Saunders, of Detroit, and is advertised as the "Plymouth Rock Mineral Well." The depth is 74 feet, the first 25 feet of which were dug and the remainder drilled. The elevation of the mouth of the well is about

0 feet, and, as the rock surface here is believed to be from 630 to 0 feet, it is likely that the well penetrated the Coldwater shales. ıe water was said to have been secured from beneath an exceedgly hard 18-inch stratum. It is reported that 3,000 gallons are sold nually, and that it has been found especially efficacious in cases of ɔumatism, kidney and bladder troubles. The following analysis, ken from the advertising circular, was made by Prof. John E. ırk, M. D., of the Detroit College of Medicine:

Analysis of Plymouth Rock mineral water.[a]

	Parts per million.		Parts per million.
assium (K)	11.58	Carbonate radicle (CO_3)	192.95
ca (SiO_2)	8.57	Calcium (Ca)	24.22
ı and alumina ($Fe_2O_3Al_2O_3$)	29.76	Magnesium (Mg)	14.36
orine (Cl)	149.43	Organic and volatile	22.25
ium (Na)	124.01		
phate radicle (SO_4)	4.31		581.44

Carbonic-acid gas and carbonate of lithium present, but not ;imated.

A similar well near the above is owned by H. P. Peters and has a pth of 80 feet, possibly also reaching bed rock. The water is said have originally flowed, and has been put on the market as "hydrorbon mineral water." Bubbles of gas, apparently carbon dioxide, e continually rising to the surface.

Flowing wells.—When the head or pressure with which these waters ıter the wells is sufficient, the water reaches the well mouth and verflows. Two belts of such flowing wells cross Wayne County, eing the continuation of similar belts in Monroe and Washtenaw ɔunties. One of these belts begins in the northwestern part of Van uren Township (secs. 3, 4, 5, and 6), extends northward across Canɔn, with a breadth of 3 miles, reaches into sec. 34 of Plymouth, and ɔntinues into the western part of Livonia Township. The belt is ɔt continuous, and nearly all of the wells that are still flowing lie to ıe east of the gravel ridge formed by the waters of Glacial Lake 'hittlesey and known as the Belmore beach. This is due to the ıct that the water does not have sufficient pressure to reach the vel of this beach, which is about 740 feet above sea level. A secad belt of flowing wells lies in the eastern part of the county, reachıg its fullest development in the southern part of Brownstown Townıip, where it is about 5 miles across. In the northern part of the ɔwnship it is interrupted. A few isolated wells occur in eastern 'aylor, in Ecorce, and in Springwells townships, where they cease ecause of the elevation of the surface on approaching Detroit. In

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States eological Survey.

Grossepoint Township, near the lake level, there is at least one flowing well. There are also scattered flows up the Huron Valley to Willow.

The average temperature of the wells of the county, as measured in May and June, is 52° F., or slightly less, but some show a rise of 1° to 3° in the fall, owing to the effect of the summer heat on pipes through which they slowly discharge. It is probable that if the bottom temperature were taken it would be found to be more constant, especially in the case of the deeper wells and wells with a weak flow. In these the waters are either warmed or cooled as they approach the surface, except at times of year when the surface temperature corresponds closely with the temperature of the bottom of the well.

To the farmers these wells are a great saving in time and expense of pumping, while the low summer temperature and constant flow are of great service in caring for milk in the dairy. The tanks do not ordinarily freeze over in winter and are thus available for the stock. The wells are about equally divided between hard and soft water, some of unusual softness occurring at Dentons, where they take the place of cistern water.

The two following partial analyses, furnished by M. O. Leighton, of the United States Geological Survey, show the relative composition of drift and rock waters at Dearborn:

Partial analyses of drift and rock waters at Dearborn.

[Parts per million.]

	1.	2.
Color	32	32
Iron (Fe)	Trace.	2
Chlorine (Cl)	19	15
Carbon dioxide (CO_2)	87.94	97.61
Sulphur trioxide (SO_3)	86	522

S. L. Lewis, analyst. 1. A. Wagner; depth, 28 feet. 2. A. Wagner (rock); depth, 115 feet.

These waters are said to produce only a very little scale in the tea kettle, even after several years' use. Simple tests show slight traces of salt, iron, and lime carbonate, but no lime sulphates, or but a trace. This condition of the water may be due in part to continuous leaching, the result of which would be to change flowing wells from hard to soft. The breaking in of new veins might, however, suddenly change the water from soft to hard. The water in the eastern belt is almost invariably charged with either iron or sulphur, along with the other minerals commonly present, owing to the nearness of bed rock. The pressure is generally low and sufficient only to elevate the water a few feet above ground level, but is somewhat greater in the western district. In the Penny well, sec. 3, Canton Township, there is a strong flow which will rise 12 feet, thus having

ı elevation of about 727 feet above tide. Most other wells in the ɜstern part of this belt indicate an elevation of 710 to 720 feet, ɔich, as a rule, drops to the southeast more rapidly than does the rface slope of the land, ranging from 6 to 12 feet to the mile within e belt. Most of the flowing wells in the eastern belt are from the d rock, and thus belong to the class next to be described. The nilarity in the character of the water would indicate that the allower wells derive their supply and head from the same source, ıd hence that the two belts of flowing wells are genetically distinct, e western coming from the drift and the eastern from bed rock. ıe table on page 70 shows the chief characteristics of this group wells.

The head and volume of the flow are reported to be on the decrease ıd the flowing well areas are being reduced. This may be due to veral causes—climatic, clogging by sand, sinking of new wells, ıd constant and useless waste of water. Nature may be expected) attend to the matter of precipitation; sand pumping and deepening ill give temporary increase of flow; but concerted action is required ı order to prevent the waste of this valuable resource. Wells that ıre not being used should be plugged and others in use should have their low reduced to meet only the immediate requirements. One driller eports that he rarely finds a farmer willing to make any reduction whatever in the size of the flow.

The following partial analysis of an unusually soft water from he parsonage well (depth 75 feet) near Denton, in the western part of the county, has been furnished by M. O. Leighton, of the United States Geological Survey. The water tested is one of the softest n the State.

Partial analysis of well water at Denton.

	Parts per million.		Parts per million.
Color	10	Carbon dioxide (CO_2)	97.61
Iron (Fe)	Trace.	Sulphur trioxide (SO_3)	.29 (?)
Chlorine (Cl)	8.75	Hardness	56.1

S. J. Lewis, analyst.

The following partial analysis of the well water at the Commercial Hotel at Wayne is furnished by M. O. Leighton, of the United States Geological Survey:

Partial analysis of well water at Commercial Hotel, Wayne.

	Parts per million.		Parts per million.
Color	19	Carbon dioxide (CO_2)	99.81
Iron (Fe)	Trace.	Sulphur trioxide (SO_3)	88
Chlorine (Cl)	15		

S. J. Lewis, analyst. Depth of well, 14 feet.

Wells in drift, Wayne County.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Quality.	Temperature.	Size of flow.	Head. Maximum.	Head. Present.	Elevation.	Remarks.
						Feet.		°*F.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*	
1	8	34	NW.	Plymouth	S. Bennett	70	Soft	51	½		0.7	720	Small amount of salt.
2	8	3	NW.	Canton	O. F. Penny	86	Hard	51.5	½	+12	3	715	Will flow a 2-inch stream.
2	8	4	NE.	do	E. Everett	35	do	51.5	½	+ 5	2.5	708	Some salt.
2	8	8	NE.	do	G. S. Bonsteel	28	Soft	52	½	+ 8	3	711	Has flowed 3.5-inch stream.
2	8	8	SE.	do	H. O. Hanford	30-35			½	+ 2.5		708	Strong in iron.
2	8	9	NW.	do	Mrs. D. Schrader	50-60	Hard	60	½	+ 2	2	708	Waters 75 head of cattle.
2	8	9	NW.	do	J. Quartle	28	Soft		½	+ 9	3	711	Made in 1868; contains salt.
2	8	31	NW.	do	S. Goddell	70	do	50	½	+ 4	2	715	Used in dairy and laundry.
2	8	30	SE.	do	J. Smith estate	50-60	do		½	+ 2		689	Free from iron.
2	8	32	SE.	do	J. F. Duntley		do	51	½		2	692	Used in dairy.
2	8	33	SE.	do	J. E. Betts	30	Hard	51			1	685	Not affected by drought.
2	8	33	SE.	do	G. Kissane		do	55	½		1.5	686	Running 15 years.
3	8	4	NW.	Van Buren	J. Couch	63		53	½		3	696	Used in dairy.
3	8	4	NW.	do	W. Deyo	42		51	½		2	693	Once flowed 49 gallons a minute.
3	8	4	NE.	do	A. Kruger	75	Soft	51.5	½		3	690	Used in laundry.
3	8	4	NE.	do	C. Nass	70		52	½		2	690	
3	8	4	NE.	do	A. Gunther	72		50		+ 4		688	Running 14 years.
3	8	5	SE.	do	W. H. Burrell	70	Soft	51	½		3	698	Used in laundry.
3	8	5	SE.	do	F. Van Tassel	48	Hard		½	+12	4	696	Has flowed 1.5-inch stream.
3	8	6	NE.	do	I. Glass	76	Soft	51	½	+ 2.5		705	Used in laundry.
3	8	6	NE.	do	C. Schlicht	72	do		½		1	706	Denton village.
1	9	18	SE.	Livonia	W. Hake	50	Medium	51			1	690	Would flow 1-inch stream.
1	9	17	SW.	do	R. L. Alexander	45	Hard	50.5	½	+ 4	2.5	693	From gravel over bed rock.
1	9	19	NE.	do	O. Melow	55	Soft		½	+12	1	680	Has flowed 2.5-inch stream.
2	11	18	SE.	Springwells	Detroit Brick Co.	80	Hard	51	1½		4	590	Flows 90 barrels a day.
2	11	20	NW.	do	L. Maples	67.5	do	52	½		3	595	Strong in sulphur.
3	11	14	SE.	Ecorse	J. Porout	78			Trickle.	+ 4	.5	599	Contains sulphur.
5	10	4	NW.	Brownstown	J. Welle	30	Hard	50.5	3	+ 7.5		589	Contains iron.
5	10	5	SE.	do	R. Smithson	28		51	1	+25		588	Iron but no sulphur.
5	10	11	SW.	do	J. Stryker	20-25			1	+10		582	Contains sulphur.

Boiling springs.—The western half of Plymouth and nearly the ıole of Northville townships are covered with ridges and knolls till, interpersed with similar masses of stratified gravel and sand, ving a very rough aspect to the country. The features are those a moraine formed at the ice margin during a temporary halt in ; general eastward retreat. The Glacial lake waters subsequently vered the lower knolls lying to the east, but elsewhere the original ughness left by the ice has been very largely retained. The ıdrained depressions common to such regions are not of sufficient agnitude to give rise to lakes of any considerable size, the largest ›ing Yerkes Lake, previously noted. Some of these lake sites ıve been filled with vegetation and are now drained, yielding a ack mucky soil especially adapted to certain crops. Securing ater from these clay knolls and ridges by means of wells is as difcult and uncertain as on the clay plains to the east, and at times ecomes impossible. The deposits of sand and gravel, however, erve as reservoirs for water, and, owing to their extent and height o the north and west, frequently yield large quantities under presıure. Along the hill slopes and in the valleys heavy natural flows ɔccur, giving rise to what are known as "bold" or "boiling" springs. They differ from the seepage springs in that they have a head, and generally stronger flow, are subject to less variation, show a steadier temperature, and yield a harder water. In numerous cases the waters are piped to dwellings and barns and yield an ideal supply, as on the Starkweather place in the southwest part of Northville Township, where a spring located in the NW. ¼, sec. 8, is piped to the house, having a fall of 16 feet, delivering a 1-inch stream and keeping 5 troughs supplied with most excellent water for stock. This water contains considerable calcium carbonate, a very little salt, and gives no reaction for calcium sulphate.

Two similar springs are utilized by the United States fish hatchery at Northville (see Pl. III, *A*, p. 44). After cleaning in 1896 the flow from the larger was somewhat more than 500 gallons a minute, but has been gradually declining since. In the fall of 1904 a second cleaning failed to increase the flow much. According to the earlier reports the temperature was 47° F., but is now 48°, with only slight variation from season to season. This is the coldest water observed in any part of the county. It is rendered hard by considerable calcium carbonate, but gives no reaction for salt or gypsum. Immediately beneath the hatchery building is a second spring which has yielded 136 gallons a minute and has a temperature of 48°. There are two flowing wells having a depth of 106 feet, which yield 1½ and 2 gallons a minute, with a temperature of 50°, but the water contains sulphur and iron and is destructive to both eggs and fish.

The villages of Northville and Plymouth are favorably situated for utilizing similar flows from springs sufficiently elevated to give the

necessary pressure without pumping. The water is cold and pure; is rendered hard by calcium carbonate; gives no reaction for gypsum, and only a slight one for salt. The supply is sufficient except during times of prolonged drought. The water is not metered and no estimates are kept of the amount used. Neither of the villages are supplied with sewers, the drainage being good in both cases. The plants are owned and operated by the villages themselves. Northville, with a population of 1,627, draws its supply from two springs in Oakland County, about 4 miles distant. The springs are about 1,000 feet apart and empty into a small receiving basin, from which the water flows by gravity, with slight fall, to a reservoir overlooking the village and 100 feet above it. The reservoir is 260 by 160 feet, with a depth of 18 feet and an estimated capacity of 2,500,000 gallons. The plant was installed in 1892–93, the village bonding for $30,000 at the time and for $8,000 later. Vitrified 12-inch crocks were first used and found unsatisfactory because of breakage and leakage, and at much additional expense were replaced with 10-inch iron casing buried 4 to 6 feet in the ground. The domestic pressure is 50 pounds and that in the hydrants 70 pounds to the square inch. There are 9 miles of mains, which consist of 4-inch and 10-inch pipes. There are 40 hydrants not paid for by the village and 325 service taps. The income derived from private consumers is about $950 per annum, and the cost of maintenance about $200. A severe test of the system was made in 1899 at the time of the burning of the plant of the Globe Manufacturing Company, when ten streams were kept playing from 3 a. m. until 2 p. m., and then three streams until evening, at the end of which time it was found that the reservoir was lowered but 18 inches.

The village of Plymouth, with a population of 1,663, has a system similar to that of Northville, its springs being in the NE. ¼ sec. 8, Northville Township, in the bottom of an old drainage channel from the ice sheet. The village has here purchased an acre of land on which an excavation 50 by 60 by 6 feet has been made, lined with cobble, and surrounded by a high wire fence. From this the water flows by gravity to a reservoir, which is located 2 miles from the village and 103 feet above it, and which has dimensions of 100 by 80 by 14 feet, giving an estimated capacity of about 500,000 gallons. The system was installed in 1893, 4¾ miles of 12-inch sewer pipe being laid at a cost of $30,000. Plymouth has had the same expensive experience as Northville, which competent advice would have prevented. The sewer pipe is now being replaced by iron casing, which will swell the expense to near $50,000. The annual income is $2,200 to $2,300, and the expense of operating about $150, aside from the fire department. There are 10 miles of mains, 60 hydrants, and 300 service taps. The average pressure is 42 to 45 pounds. It is estimated that 75 per cent of the population use this water, the remainder

WATERS FROM BED ROCK.

GEOLOGIC FORMATIONS.

Beneath the mantle of clay, sand, and gravel, resulting from the joint action of wind, water, and ice, there lies a series of stratified rocks, consisting of sandstone, shale, limestone, and dolomite. In past geologic ages these beds were formed in the sea, in approximately horizontal layers, but they were early upheaved and tilted, so that their edges have a general northeast trend in Wayne County, and the beds themselves dip to the northwest at the rate of some 30 to 35 feet to the mile. They still retain some of the minerals belonging to the concentrated brines of the primitive seas, and others deposited at the time the rocks were forming or subsequently. These beds supply a limited part of the county with a more or less highly mineralized water, much of which flows, but some of which must be pumped. The youngest and highest of this series of beds in Wayne County cuts across the northwest corner. It consists of shales, with some sandstone, and is known in the State as the Coldwater shale (Waverly and Cuyahoga). Beneath this lies the dark Antrim shale (Genesee), generally yielding gas and faint traces of oil. Next in order come the bluish beds of shale and limestone, making up the Traverse group (Hamilton), and frequently referred to as "soapstone;" beneath which lies a solid, light-gray limestone known in the State as the Dundee (Corniferous). Below this limestone is a drab dolomite, the Monroe group (Lower Helderberg), which drillers do not ordinarily separate from the preceding. Embedded in it and of the same geologic age is the so-called Sylvania sandstone, a pure glass sand, cutting across the extreme southeastern part of the county; this is the oldest of the formations reached directly beneath the clay in the county. Still older and lower, however, and coming near the surface in Monroe County and bordering parts of Ohio, lie, in order, the Monroe beds below the Sylvania sandstone (Lower Helderberg and Salina), the Niagara, Medina, Hudson, Utica, and Trenton, the last being the oldest bed reached by borings in the county.

WATER SUPPLY.

Flowing wells.—The wells of this class comprise most of those in the eastern belt described above (p. 67). They are heavily mineralized, as a rule, and frequently rendered rank by sulphur and iron. The average temperature is 51.4°, as compared with 52° for the flowing drift wells, but rises slowly as the water comes from greater depth. Theoretically the temperature should be still more constant than in the drift wells, but it must be affected in the same way and to the same extent as it rises to the surface. With reference to the level of the ground the head is *generally* slight, ranging from a mere

rise to the surface to 15 and 25 feet above in exceptional cases. At Dentons, in a well along the railroad track, the water is reported to have reached the second story of a building, indicating its rise to about 715 feet above sea level. The Swan well on Grosse Isle is the easternmost of the flowing wells in the county and has a head of 597 feet. Measured between these two extreme wells the average reduction in head toward the southeast is 5.6 feet to the mile. Between the Flat Rock wells and those on the lake shore the average reduction per mile is 3.5 feet. Although the rock strata are dipping to the northwest, these facts indicate that the source of supply is to the west, as pointed out by Fuller in his report on the failure of wells along lower Huron River (p. 37).

The table on page 76 gives the principal data concerning the flowing wells from bed rock. The most wonderful of the entire set is the Swan well, described by Fuller (pp. 43–44), which flows 3,000 gallons a minute, or 4,320,000 gallons a day—enough to supply several times over the entire river front from Trenton to Detroit. It has recently been stated in the papers that the Grosse Isle Mineral Company has been organized to put the water on the market under the name "Kathairo" (see p. 44 for analysis).

Springs.—In the Brownstown region of flowing wells there are numerous natural flows charged with iron, sulphur, calcium sulphate, calcium carbonate, and sometimes considerable salt. These are most numerous along Huron River, from Flat Rock to Lake Erie and northward to Gibraltar. The water is generally too rank for use and is believed to come from bed rock, having made for itself a natural channel through the clay. Such springs are found in Brownstown as follows: T. 4 S., R. 10 E.: NE. ¼ sec. 28, SW. ¼ sec. 30, SE. ¼ sec. 31, NE. ¼ sec. 36. T. 5 S., R. 10 E.: SW. ¼ sec. 5, NE. ¼ sec. 9, SE. ¼ sec. 13, NW. ¼ sec. 1, eastern and southern portions of sec. 24. An analysis of the "Wyandotte White Sulphur Springs," the location of which is unknown to the writer, is given by Peale[a] and is quoted by Lane.[b]

Nonflowing wells.—The principal facts relating to the nonflowing wells from rock have been grouped together in the table on page 77, from which the character of the water from the various geologic horizons may be seen at a glance. The water is generally hard and highly mineralized. In a few cases only is it reported to be soft. Time did not permit the securing of records of the temperatures of the water of these wells, but owing to the fact that it stands more quietly in the pipes, frequently not far from the surface, it is undoubtedly more variable than in the artesian wells. The head of these rock waters also drops as we pass eastward. The following analysis of the water

[a] Peale, A. C., Lists and analyses of the mineral springs of the United States: Bull. U. S. Geol. Survey No. 32, 1886, p. 150.

[b] Lane, A. C., Lower Michigan mineral waters: Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey 1899, p. 72.

from an 850-foot well at the Wayne County Infirmary at Eloise shows how heavily charged with minerals these waters may become. The well was drilled for gas by C. C. Nims. The Traverse group was struck at 130 feet (the elevation of the well mouth being about 625 feet) and yielded a flow of fresh water. The well passed through this formation and the underlying Corniferous and entered the Monroe group, from which a strong brine was secured, with some suggestions of oil. The analysis was made by Dr. S. P. Duffield, of Detroit, April 18, 1888.

Analysis of water from salt well, Wayne County Infirmary, Eloise.[a]

	Parts per million.
Calcium (Ca)	9,714.65
Carbonate radicle (CO_3)	3,970.25
Magnesium (Mg)	150.17
Sulphate radicle (SO_4)	12,354.88
Chlorine (Cl)	40,214.11
Sodium (Na)	25,354.54
Total solids	91,758.60
Hydrogen sulphide	405

These highly charged mineral waters are used for bathing purposes at two places in Detroit—the Clark Riverside bath house and the Detroit sanitarium. The well at the latter place has a depth of 307 feet, entering the Corniferous, and yields a mineral water strong in sulphur. The depth of the Clark well either is not known or has not been given out, but it is probably not very different from the other. An analysis of its water is given by Lane.[b] Along Detroit River from Delray to Trenton artificial brines are made by forcing water to the salt beds of the lower Monroe series, where they dissolve the solid rock salt and flow to the surface. The salt is then secured by evaporation or used in the manufacture of soda, soda ash, and bleaching powder. The most promising horizon for securing a supply of fresh water is the Sylvania sandstone, a porous bed of pure sand rock holding an abundance of water. Although fresh, it is liable to contain sulphur and iron, carried up from the dolomites of the underlying Monroe group. In the northern part of Monroe County and the southern part of Brownstown Township this bed lies immediately beneath the clay and furnishes an abundance of good water. In the 6 miles to Trenton it drops to 280 feet below the surface, or at the rate of about 40 feet to the mile. Toward Wyandotte the bed thickens, with practically no dip, and in the Eureka well it was reached at 230 feet, while in a well of the Michigan Rock Salt Company at Ecorse it was reached at 220 feet. Beyond Ecorse it drops rather rapidly again, having an average thickness of 99 feet in ten wells of the Solvay Company at Delray.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Op cit., p. 73.

Flowing wells in bed rock, Wayne County.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Diameter of discharge pipe.	Temperature.	Depth to rock.	Remarks.
						Feet.			*Feet*	*Inch.*	*° F.*	*Feet.*	
3	8	6	NE.	Van Buren	Bandy	125	Coldwater	Soft	705			81	Village of Denton.
2	8	28	NE.	Canton	M. Carleton	140	Antrim	Salt and iron	682	(a)		70	Gas; not usable.
2	11	18	SW.	Springwells	A. Lapham	129	Traverse	Hard	588	½	52	100	Strong in sulphur.
3	10	34	SW.	Taylor	J. Shetrum	86	Corniferous [b]	Sulphury	603			83	Now rises 4 feet.
2	11	4	SW.	Springwells	J. C. McDonald	250	do	Hard	605	½	53	125	Rank in iron and sulphur.
3	11	30	SW.	Ecorse	Beaubien	64	do	do	587	½	51	64	Strongly mineralized.
3	10	35	NE.	do	Unger		do	do	598	½	51		Minerals abundant.
4	10	13	SE.	Monguagon	Duman	30	do	do	580	½	52	2	Strongly mineralized.
4	10	25	NW.	do	E. Lathrop	12	do	Sulphury	578	½		10	
4	10	3	NE.	Brownstown	Clark	68	do	Hard	597	½	51		Mineralized.
4	10	3	NW.	do	G. McDonald	76	do	do	602	½	52	76	
4	10	4	NE.	do	J. G. Carson	65	do	do	603	½	51		Strongly mineralized.
4	10	28	SE.	do	J. Crooks		do	do	593	½	51		Reduced by Rockwood deep well.
4	10	33	NE.	do	Brown	30	do	do	594	½	51	28	Do.
2	10	1	SW.	Dearborn	W. Robertson	357	Monroe	do	611	½	52	100	Rank in sulphur.
2	11			Ecorse	Detroit Salt Co.	1,096	do	Sulphur	582			95	Sulphur water at 223 feet.
2	11			do	Brownlee & Co.	1,200	do	do	578			82	Strong sulphur vein at 168 feet.
5	10	3	SE.	Brownstown	Richardson	31	do	Hard	582	1½	51	28	Sulphur; only little salt.
5	10	8	NE.	do	B. Hall, sr.		do	do	587	½	51		Iron and sulphur; little salt.
5	10	9	NW.	do	E. T. Wood	22	do	do	587	½	55	22	Do.
5	10	9	SE.	do	Doctor Reed	17	do	do	588	1½	50		Do.
5	10	9	SE.	do	Metzger	32	do	do	588	½	50	12	Iron and sulphur. In Rockwood.
5	10	10	SE.	do	Quillin	28	do	Iron	581	½	51	26	
5	10	11	SE.	do	Navarre estate	60	do	Sulphur	581	½		25	Sand overlies limestone.
5	10	11	SW.	do	J. Stryker	20–25	do	Sulphury	582				Has risen 10 feet.
5	10	12	SE.	do	J. Woodruff	30	do	Hard	578	½	51		Mineralized.
5	10	14	SE.	do	T. Campau	32	do	do	578	½	52	14	But little salt.
5	10	15	NW.	do	J. Ferguson	Inc.	do	do	585	(c)	51	18	Heavy sulphur vein at 300 feet.
5	10	23	NE.	do	M. Newell	32	do	Sulphur	577	½		20	Some iron.
5	11			Grosse Isle	J. Swan	2,375	Trenton	See analysis	575		52	17	Flows 50 gallons a second; head, 22 feet.

[a] Trickle.

[b] Corniferous—Dundee.

[c] 1 foot by 6 inches.

Township.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Head.	Depth to rock.	Remarks.
						Feet.			*Feet.*	*Feet.*	*Feet.*	
2	8	27	NE.	Canton	B. Barker	132	St. Clair	Very salty	677	−12	100	"Water will support an egg."
1	9	35	NW.	Livonia	C. Kinney	80	do	Fresh	636	− 8	70	Considerable gas.
1	9	24	SW.	do	F. Schroeder	160	do	Medium	635	−25	65	Water abundant.
2	9	15	SW.	Nankin	C. Schultz	97	do	Rather soft	652	− 2	77	Some gas at first.
2	9	10	NE.	do	W. Dickinson	110	do		639	− 4	50	Some little gas.
1	10	22	SE.	Redford	J. F. Chavey	82	do	Hard	628	−17	73	Flowed at first; some gas.
1	10	25	NW.	do	A. David	116	do	Salt and sulphur	630	−10	72	Heavy gas flow at 114 feet.
1	10	23	NE.	do	J. F. Stahelin	93	do	Hard	633	− 6	80	Still yields gas.
1	10	13	NW.	do	G. Miller	107	do	Medium	647	−30	80	Considerable gas.
1	11	1	SW.	Greenfield	C. and E. Roberts	127	do	Very soft	632	−14	124	Iron and gas; good supply.
1	11	11	SW.	do	Log Cabin dairy	126	do	Salt and magnesia	643	−26	90(?)	Five wells about the same.
1	11	13	SW.	do	Stevens estate	156	do	Hard	640	−12		Heavy flow of gas at first.
1	12	8	NE.	Hamtramck	W. S. Thomas	163	do	do	628	−19	146(?)	Salty; gas at 100 feet and 158 feet.
1	12	15	NE.	do	Store	137	do		623	−20	130	Used in greenhouse; little gas.
1	12	9	SW.	do	E. A. Norris	170	do	Salt	627	−25	160+	Some gas.
1	12	16	NW.	do	H. Arbeter	162	do	Salty	627		140	Little gas.
1	12	12	SW.	do	G. Brinckman	147	do	Soft	615	− 8	130	"Good as cistern water."
1	12	15	SE.	Grossepoint	J. Brinckman	143	do	Sulphury	615	−12	138	Neither salt nor gas.
1	12	15	SE.	Hamtramck	Pelky	141	do	Soft	615	− 8	140	"Regular river of water."
1	12	23	NW.	Grossepoint	J. S. Sullivan	200	do	No water	600		160	Some oil and gas.
1	13			do	A. K. Kiefer	133	do	Hard	586	− 7	110	On lake shore; some salt.
1	13			do	Claire View farm	162	do	Salty	587	−12	112	Abundant; near lake shore.
3	8	11	NW.	Van Buren	Wm. Stirling	160	Traverse	Soft, milky	680	−17		Sulphur and iron; stock only.
3	8	21	SE.	do	S. Campbell	183	do	Magnesia	678	−18	99	Belleville; good flow at 96 feet.
3	8	24	SW.	do	Sanitary works	250	do	Salty	660		175	Well abandoned.
2	10			Dearborn	Arna mills	140	do	Sulphury	620	−30	140	Not usable in dyeing.
1	8	26	SW.	Plymouth	Plymouth well	280	do	Salt	730	− 2	100	One vein rose 2 feet above surface.
1	10	5	NW.	Redford	Rodgers	336	Corniferous		640	− 3	90	Flows at 94, 150 and 200 feet.
2	9	28	SW.	Nankin	Wayne	305	do	Sulphury	638	−60	157(?)	Water at 220 feet; some gas.
2	12			City	Detroit	268	do	No water	600		127	Old test well in 1829.
2	12			do	Sanitarium	307	do	Sulphury	595		120	Strong mineral water.
3	8	17	NE.	Van Buren	D. L. Quirk	383	Monroe		703		100	Water only at bottom.
2	9	26	SW.	Nankin	County house	850	do	Salt	625	− 9	130	Fresh water over rock.
1	12	5	NW.	Hamtramck	C. Krause	996	do		635		180	Gas reached at 100 feet.
3	9	12	NW.	Romulus	E. Twark	1,820	Niagara	Salt	632	−18	95	Fresh vein at 125 feet; sulphur at 220 feet.

WATER SUPPLIES OF LENAWEE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

This county is the second west of Lake Erie on the southern borde of the State. Its southeastern part is a plain once occupied b Glacial-lake waters, while its northwestern part is traversed by series of moraines trending northeast and southwest. Most of th county is tributary to Raisin River, which crosses the northwes corner and also the eastern part. The southwestern part of th county is tributary to Tiffin River, also called Bean Creek. Th four northwestern townships have an average altitude of about 1,0 feet, with points that exceed 1,100 feet. South and east of the townships there is a gradual descent through the morainic tracts about 800 feet at the edge of the old lake plain, which, in tur drops to less than 700 feet at the edge of the county.

It is a topography well calculated to give artesian conditio The drift beds dip eastward with the slope of the surface, and wat which is absorbed in the elevated northwestern section is und strong hydrostatic pressure as it passes into the low southeaste part. The flowing wells are found on the lake plain and also sags and narrow plains between morainic ridges. In places on t lake plain, either through the absence of a water bed or throu the fineness of its material no flows are obtained, thus breaking the flowing-well territory and forming several somewhat indepe dent areas. Further exploration, however, may so extend the areas as to run them together, leaving only comparatively sm island-like tracts where the beds do not contain a good supply water.

Wells have been sunk to rock at Cement City, in the northwe corner of the county, where a good supply of water is found in san stone at depths of 65 to 70 feet. There are also numerous wells the eastern end of the county that have reached rock, which found at depths of 80 to 150 feet. In the district south of Blissfie the wells are often carried through shale to limestone at about 2 feet, but from Blissfield north the wells generally obtain a supp near the top of the rock if none has been found in the drift. We in the vicinity of Clinton, Tecumseh, and Adrian that have be drilled to rock find a salt water, unsuitable for drinking. In mu of the central and western parts of the county there are no borin deep enough to strike rock.

The writer's studies of water supplies were made chiefly in 18 in connection with the mapping of moraines, shore lines, and oth features of surface geology, and only brief notes were taken as

ıe extent of flowing-well districts, depth and strength of flowing ·ells, and such other data as chanced to be readily available. This esulted in a general acquaintance with each of the tracts in which lowing wells are obtained, but hardly formed sufficient basis for , report. Mr. Jon A. Udden made a special investigation of each lowing-well district in 1904, and prepared the tabulated data given ɔelow. The public supply of Hudson was also examined by Mr. Udden, but those of Adrian and Tecumseh were examined by the writer.

WATERWORKS.

ADRIAN.

The Adrian water supply is in the hands of a private company. At one time wells were in use, but the entire supply is now pumped from South Fork of Raisin River, which flows through the city. In the dry seasons the stream carries about 6,000,000 gallons a day, and the waterworks at times use one-third of the flow. Some dissatisfaction is manifested by the residents, because of the quality and of the limited quantity of the low water of the stream. The supply from wells also proved inadequate and tests made by the water company have not yet resulted in the discovery of an adequate supply from wells. One well sunk to a depth of 1,980 feet gets a salt water, with some gas at about 500 feet.

The following analysis was made by Dr. A. B. Prescott, at the University of Michigan:

Analysis of water at 500 feet in deep well at Adrian waterworks.[a]

	Parts per million.		Parts per million.
Magnesium (Mg)	67.29	Potassium salts	Trace.
Calcium (Ca)	249.51	Phosphates	Trace.
Chlorine (Cl)	7,095.02	Sulphates	Trace.
Bicarbonate radicle (HCO_3)	483.98	Silica	10.14
Aluminum	7.19		
Lithium	Trace.	Total solids	7,923.13

H_2S gas, 160 c. c. per liter. Reaction alkaline. Specific gravity 1.0093.

The drift, which is mainly sand, is 180 feet thick and contains fresh water. Another well was dug, 24 feet square and 9 feet deep, and then bored with a 12-inch auger to 78 feet. This well barely flows, though at a level only 3 or 4 feet above the stream and nearly 10 feet below the waterworks station. When first made it yielded by pumping 750,000 gallons a day, but got so clogged with sand as to greatly diminish the yield, and is now abandoned. The temperature of the water as it flows from the pipe is 51.75° F. The water from this well is hard and chalybeate.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at United States Geological Survey.

STATE INDUSTRIAL HOME FOR GIRLS.

The State Industrial Home for Girls, located in the north part of Adrian, has an independent supply for drinking, cooking, and bathing, obtained from three wells on the grounds. The Adrian Water Company furnishes the supply for closets, lawn sprinkling, and fire protection. About 350 inmates and 50 officers and other employees are supplied from the wells.[a]

HUDSON.

The village of Hudson has municipal waterworks, built in 1890, and supplied from a group of tubular 6-inch wells 70 to 80 feet deep, in Bean Creek valley. The water rises in these to within 20 feet of the surface. The supply is 500,000 gallons a day and is highly esteemed by the residents. The pumps have a capacity of 2,000,000 gallons, but the consumption is less than one-half million a day. The ordinary pressure is 45 to 50 pounds and the fire pressure 80 to 90 pounds.

TECUMSEH.

Tecumseh, which is located on a gravel plain traversed by Raisin River, obtains its supply from a large excavated well about 35 feet deep, sunk into the gravel. The water is pumped to a standpipe 120 feet high. The village first constructed waterworks in 1877 and rebuilt in 1892. The well from which water is drawn is in the thickly inhabited southern part of the village, near the bluff of the river. It seems to be favorably situated to receive contamination from the cesspools around it, and should be abandoned as soon as a supply can be secured from a better source. The prospect for obtaining an adequate and safe supply just above the village seems good, for the gravel there is saturated with water as fully as inside the village limits.

MISCELLANEOUS VILLAGE SUPPLIES.

So far as known, no other towns of the county have yet developed public supplies. The village of Morenci is, however, contemplating a supply from flowing wells. Weston has fire protection for business houses in a tank which is kept in order by the business men. This is filled by a windmill from a public well and connected with a hydrant and hose attachment. Clinton also has fire protection in the business portion of the village, there being a distribution system paid for by abutting property owners, into which water is pumped by the Woolen Mill Company free of charge, Raisin River being the source of supply.

[a] Data supplied by Mrs. Mary Sickels, superintendent of the home.

At Clayton the common depth of wells is 30 feet, but the wells nge from 20 to 70 feet. The water is from gravel veins in till. At ement City, or Woodstock, wells are generally drilled 65 to 70 feet nd obtain water in sandstone. In places the drift is only 10 feet nick. At Addison wells are commonly dug about 30 feet and obtain n ample supply of water in gravel or sand under till. At Onsted the ug wells are 20 to 25 feet deep, and the tubular 80 to 160 feet. Water is abundant, especially in the tubular wells. At Clinton wells re about 30 feet deep, some being dug and others driven. The water s found at about the level of Raisin River. The wells are through gravel and sand from top to bottom in the western part of the village, being in a line of glacial drainage. The eastern part of the village is on the slope of a moraine, and wells there are through till and in some cases have been driven to considerable depths. At Britton wells are usually 20 to 30 feet deep, and in some cases 50 feet or more. A few on the lowest ground flow, and in the rest water rises nearly to the surface.

At Ridgeway the wells are usually shallow, water being obtained at the base of the beach gravel at about 15 to 20 feet. A few tubular wells have been driven to considerable depth to test for flowing wells. The fine sand encountered is difficult to screen, and thus far wells have not yielded a flow. Flowing wells are obtained, however, within a short distance from the village along the same lake beach as that at the village. At Holloway and Raisin Center essentially the same conditions prevail as at Ridgeway. The water level in the tubular wells seems to be slightly lower than the beach on which the villages stand, so that flows are not obtained.

At Blissfield wells are often drilled to the bottom of the drift, 100 feet or so, there being a compact clay from top to bottom. The water found at the base of the drift and that in the upper part of the rock has enough salt to be noticeable in the tests, but not enough to make the water objectionable for drinking. The head in these deep wells is nearly level with the surface, and one well (that of W. E. Gelson) flows with a head of 2 feet above the surface. It is 80 feet in depth and is situated on the north side of Raisin River, at an altitude of 683 feet above tide.

At Deerfield wells are about 40 feet deep, or to the level of Raisin River. A few wells in the vicinity of the village have been driven to the base of the drift, about 85 feet, and have a head near the surface.

At Fairfield and Jasper wells are usually obtained at 20 to 30 feet and the head is only a few feet below the surface. The gravel-beach ridges in places yield water at the base, but usually wells are drilled a short distance into the till. According to information obtained by

Mr. Udden, a well which was put down at Jasper by Ed. Service to a depth of 158 feet passed through clay 108 feet, dry gravel 14 feet, brown clay with small shells 23 feet, gravel 3 feet. The water in it rises to within 6 feet of the surface and is salty. At Weston the wells are about 20 feet deep and obtain water in gravel under clay.

Other villages in the southern part of the county depend largely upon shallow dug wells, except Morenci, which, as indicated below, has a large number of tubular flowing wells. The entire district seems to have large quantities of water at only 50 to 100 feet depth, or within easy reach of tubular wells, and these should be substituted for dug wells.

FLOWING WELLS.

YORK DISTRICT.

The York flowing-well district comprises about 14 square miles in northeastern Lenawee, northwestern Monroe, and southern Washtenaw counties (see fig. 4, p. - -), and includes the village of York, in Washtenaw County, whence its name is derived. The wells within the village appear in fig. 5. The extent and general conditions were examined by the writer in 1903, but a more detailed study was made in 1904 by Mr. Udden, who tabulated the data presented below. Samples of water near Milan were examined by Mr. Lewis sufficiently to determine that what is termed soft water is only relatively so, most of the water being very hard; it is in this sense that the terms should be understood.

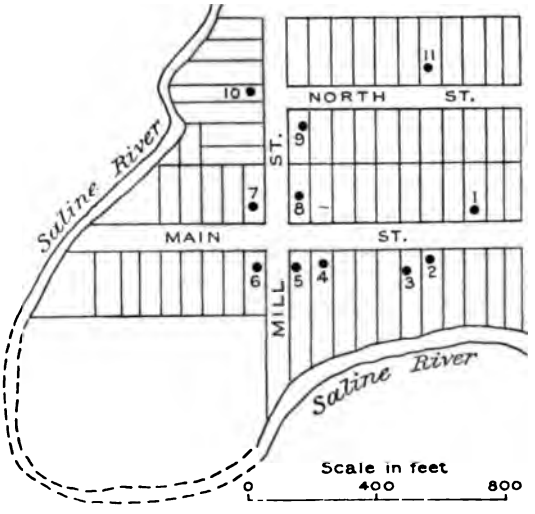


FIG. 5.—Plat of York village, showing distribution of flowing wells.

This district lies along the Belmore beach, which has a uniform altitude of about 738 feet along its crest. Taking this as a datum, Mr. Udden worked out with some precision the height to which water rises, though he did not thoroughly bring out the fact that in not a few wells it will rise several feet higher than its present point of escape. It will rise to 720 to 725 feet on the southeastern edge of the district and to 755 to 760 feet on the northwestern—a difference of 30 feet or more in the 3 miles

oss the district, a loss of head of at least 10 feet a mile in a itheastward direction, corresponding closely with the most rapid pe of the surface. In this connection it is of interest to note that McIntyre well, in Macon Township, Lenawee County, which is oldest well in the field (made in 1834), is still flowing at an altitude 758 feet, or about as high as any well in the district. This seems indicate that there has been little if any lowering of head through development of the field. There have been only a few instances the cessation of a flow, and in nearly all, if not in all, of these es the cessation seems due to clogging.

The catchment area is probably found in the morainic tract to the rthwest, with perhaps some additions from the lake plain between moraine and the wells. As a rule the lake plain is underlain by lay so compact that it will absorb but little water, but the moraine a looser-textured drift that should absorb a large amount.

The wells usually pass through considerable blue clay before reach- the water bed that yields a flow. The water beds appear to be ter developed near the bottom of the drift, yet some very strong lls have been obtained in its upper part. The water seems to rise out the same in wells that are near together whether the water is the upper or the lower part of the drift or in the rock, there being ch less difference on account of stratigraphic position than on ount of geographic position. This fact seems to indicate that the derground waters at the various levels have connection with or rce in the same catchment area. Possibly beds at various levels ve connecting porous beds, for in the drift deposits the porous or ter-bearing beds have very irregular distribution.

A few wells have been carried a short distance into rock, but the ality of water and the head are so similar in such wells to those in ighboring wells supplied from the drift that the water seems likely be contributed by the drift deposits. The rock surface is some- at uneven, being in places within this district as low as 550 feet d in other places over 600 feet above tide. The wells obtaining supply from the rock usually reach it where its altitude is highest, r the depressions in the rock surface seem generally to have been lled with sand or gravel.

The temperature of wells that have a rapid flow and but little xposure of pipe is 51.5° to 52° F., and those with higher tempera- ures seem to have acquired them through surface conditions, for he temperatures were taken in hot weather. In cold weather the xposed pipes in weak wells are liable to be cooled sufficiently to ive the water a temperature below that reached by stronger flows or those with little exposure of pipe.

In but few cases has the addition of new wells caused a decrease in flow of those in operation. By distributing wells properly a much

larger number could be made without taxing the limits of the field. It so happens that in York village and in some cases on the farms new wells are needed within short distances of those in operation. It will be advisable in such places to reduce each well to a discharge that simply meets the needs of the owner. To restrict strong flows, even if remote from other wells, should be the practice, for the distance to which a flow will draw down a supply may be great under certain conditions, and the owner himself will have less waste water for which to provide drains.

There is a small group of flowing wells in sec. 17, York Township, in the valley of an eastern tributary of Saline River, which are somewhat distinct from the main district. However, it is probable that flows could be obtained between these wells and the main district by following the valley through secs. 18 and 19, though the uplands bordering the valley in these sections are too high to furnish flows. These wells are included in the tabulated data given below.

Wells in York flowing-well district in Lenawee, Monroe, and Washtenaw counties.

MACON TOWNSHIP, LENAWEE COUNTY.

Section.	Part of section.	Owner.	Year of finish.	Diameter.	Depth.	Elevation.	Water rises to.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Cost.
				In.	*Ft.*	*Ft.*	*Feet.*	*Gals.*	*°F.*		*Feet.*	
1	NE. ¼	Alfred Lewis[a]		2	100	737	737	.5	.....	Soft	99	$76.00
1	E. side	Morton Phillips		2	40	725	727+	1	52.5	Hard	.....	.....
1	Center	do	1874	2	40	725	727	.....	.....	do	.....	.....
1	Center	A. Hall	1880	1	50	725	727+	1	53.5	Soft	.....	.....
1	Center	do	1903	2	135	730	733	1	51.9	do	.....	100.00
1	NW. ¼	[illegible]	1892		83	740	742	.75	53		.....	.....
1	NW.	[illegible] Young		2	...	740	742	.5	53.5	Hard	.....	.....
1	NW.	do	1903	2	50	740	742	.....	.....	do	.....	.....
1	SW. ¼	W. L. Lester	1880	2.5	18	736	739	5	52	Soft	.....	.....
1	SW.	Lewis Harmon	1886	2	18	736	740	.5	52	do	.....	.....
1	SW.	do	1874	2	48	736	740	1	.....	do	.....	.....
1	Center	[illegible] Fellows	1886	1.5	132	735	737+	1.5	52.5	Hard	.....	31.00
2	NE. ¼	[illegible] Martin		2	.....	740	743	.5	53	do	.....	.....
2	E. side	[illegible]		2	.....	738	741	.5	53	do	.....	.....
2	SE. ¼	M. M. Dillon		1.5	60	740	742	1.5	51.5	do	.....	.....
2	SE. ¼	[illegible]		1.5	45	735	737+	1	52	do	.....	.....
2	Center	D. Lover[b]		2	50	740	742	1.5	52	do	.....	.....
2	[illegible]	[illegible]		2	45	740	742	1	52	do	.....	.....
2	NW. ¼	C. J. Colpo		2	...	750	752	3	53	do	.....	.....
11	SE. ¼	John Smith			156	740	742	.....	53	do	.....	.....
11	SW. ¼	C. McIntyre[c]	1884	1	...	756	758	.75	52	do	.....	.....
11	SE. ¼	J. Henderson	1884	1	36	755	757	.75	52	do	.....	.....
11	SE. ¼	Mrs. David Bond		2	...	736	741	1.5	52.5	Soft	.....	.....
11	SE. ¼	A. Boyd		2	112	739	[illegible]	1.5	53	do	.....	.....
11	SE. ¼	G. Hausman		2	122	735		5	52	do	.....	.....
11	SW. ¼	John Smith		2	.....	737	[illegible]	.....	54	Hard	.....	.....
12	NW. ¼	Amon Harmon[e]			.....	730	[illegible]	.....	51.6	Soft	.....	.....
12	NW. ¼	F. Whating	1887		402	729	731+	1	52	do	.....	.....
12	W. side	S. L. Henry[d]	1894	2	127	735	737+	.37	53	do	126	.....
12	W. side	School well[e]	1893	2	125	730	733+	9	52.5	do	125	.....
12	W. side	Sam. Gibson[f]	1898	2	208	718	721+	1.5	52	do	.....	.....
12	S. side	Sam. Boyd	1894	2	102	718	721	.....	53	do	.....	.....
12	NE. ¼	Alfred Lewis	1900	2	36	722	725	1	52	do	.....	30.00
13	NW. ¼	A. Hoagland[g]	1903	2	122	720	723	.....	.....	Hard	122	.....

[a] The Lewis well penetrated sand 12 feet, blue clay 55 feet, gravel 30 feet, and entered limestone 1 foot.

[b] The McIntyre well is probably the oldest flowing well in southeastern Michigan.

[c] The Harmon wells are five in number, all shallow, but varying in rate from 1 quart to 2 gallons a minute. One had an original water elevation of 745 feet.

[d] The Henry well had an original water elevation of 741 feet; it entered limestone about 1 foot.

[e] The schoolhouse well had an original water elevation of 741 feet; it entered limestone 1 foot.

[f] The Gibson well had an original water elevation of 740 feet; it penetrated clay 30 feet, gravel 28 feet, and quicksand 50 feet.

[g] The Hoagland well struck limestone at bottom; it penetrated blue clay 120 feet and gravel 2 feet.

York flowing-well district in Lenawee, Monroe, and Washtenaw counties—Continued.

MACON TOWNSHIP, LENAWEE COUNTY—Continued.

t of ion.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth of rock.	Cost.
			In.	*Ft.*	*Ft.*	*Feet.*	*Gals.*	*°F.*		*Feet.*	
side..	George East	1893	2	108	718	721+	Weak.	53			
. ¼..	J. Harrington		2		735	737	1	53			
side..	Louis Feldman [a]	1899	2	125	728	731	1.5	53	Soft	122	$60.00
side..	Warren Miller	1895	2	122	728	731	.75	53	Hard		
. ¼...	Tom Boyd [b]	1900	2	117	728	730	.75		Soft		55.00

MILAN TOWNSHIP, NORTHWESTERN MONROE COUNTY.

. ¼..	School well		2		737	738	Weak.	55			
side.	W. Young	1902	2	63	725	729	.75	52	Soft		$40.00
side.	do		2	60	725	728	5	52			
ide..	F. Holcomb (2 wells)		2		719	725					
side..	W. C. Sanford [c]		2	165	718	725	3	52	Hard		
ter..	J. H. Vescelius [d]		2	127	730	730	Weak.		do		
. ¼...	W. Gauntlett		2		725	728					
. ¼..	R. J. Gregg	1901	2	45	722	726	4	52	Soft		
side.	Henry Dibble			90	720	721+	.62	52	do		
. ¼...	John Mooney	1884	2	111	718	721+	.25	52	do		90.00
. ¼...	John Burnett		2		718	721+					
. ¼...	Glen Hubbard		2		718	721+					
. ¼...	James Kinch		2		718	721+					

SALINE TOWNSHIP, WASHTENAW COUNTY.

. ¼...	F. Dieterle	1896	2	94	734	741	1	52.3	Soft		
. ¼...	M. Eberling		2		740	743	15	52	do		
¼...	A. M. McKenny [e]	1884	2	90	735	738+	Weak.	51	do		
ide..	C. Bacon		2		738	740	Weak.	53	do		
ide..	J. L. Harris [f]	1903	2	138	740	760	20	52	do		
. ¼...	Elias Olds [g]		2	126	740	746	.5	54.8	do		

YORK TOWNSHIP, WASHTENAW COUNTY.

ter..	A. Acton [h]	1890	2	52	750	755	2	52	Soft		$50.00
side.	A. J. Lawrence				753	755	1	52	do		
side.	W. McKendry [i]	1896	2	106	750	752	Weak.		do		50.00
ide..	J. M. Clark [j]	1890	2	140	740	743	.5	55	do		60.00
side.	E. L. Dennis	1903	2	123	740	744	1.5	54.5	do		
ter..	Frank Gooding		2	123	735	739+	50+=	51.5			
¼...	Lee Draper		2		735	739	1	56			
ide..	John Kellog [k]	1892	2	170	735	737	Weak.	54	Soft	168	170.00
. ¼...	Ed. Alchin [l]	1894	2	129	735	739	.75	52	do	129	
. ¼..	J. N. Lawrence [m]		2	118	734	738	3.5	52			
ter..	F. S. Olds [n]	1894	2	153	735	740	1.5	52	Soft		60.00

Feldman well had an original water elevation of 743 feet; it carries a little oil from the lime-
t penetrated blue clay 25 feet, sand and gravel 92 feet, hardpan 1 foot, sand 4 feet, and limestone

Tom Boyd well penetrated blue clay 15 feet, and was then in sand to bottom. The water is
ower part of the sand.
Sanford well, on farm owned by John Campbell, enters rock 55 feet and is cased to the rock.
Vescelius well is thought to have struck rock at bottom.
McKenny well penetrated clay loam 21 feet, sand 4 feet, blue clay 86 feet, sand and gravel 4 feet.
Harris well struck a weak water vein at 118 feet with head of 1 foot, and a strong flow at 138
ravel with a head of 20 feet.
Olds well penetrated clay 106 feet and sand 20 feet.
l 15 feet, blue clay 35 feet, gravel 2 feet, water has slight sulphur taste.
well overflowed and was filled, and the 2-inch well sunk near it.
l 20 feet, blue clay 129 feet, hardpan crust with sand and gravel beneath, yielding water.
w 1 gallon a minute; gravel 4 feet, blue clay 129 feet, quicksand 35 feet, shale rock 2 feet.
wells of Alchin and Lawrence interfere with each other. The Alchin well penetrated sand
clay 109 feet, and apparently struck rock at bottom.
cksand 90 feet, blue clay 26 feet, hardpan and gravel 2 feet. At 90 feet a small flow of gas was

ch gravel 12 feet, blue clay 136 feet, quicksand 5 feet. Temperature 51° when made; consid-
iron.

Wells in York flowing-well district in Lenawee, Monroe, and Washtenaw counties—Continued.

YORK TOWNSHIP, WASHTENAW COUNTY—Continued.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth to rock.	Cost.
				In.	*Ft.*	*Ft.*	*Feet.*	*Gals.*	*° F.*		*Feet.*	
22	SE. ¼	C. Harrington [a]		2	115	718	722	.4	56	Soft		
23	NW. ¼	B. F. Davis	1894	2	144	737	739	.16	54			
28	NE. ¼	A. McIntyre	1892	2	124	730	734	3.5	52			$48.50
28	NE. ¼	D. C. Newcomb		2	117	727	730+	1	52			
28	NE. ¼	A. Woodmanse [b]	1894	2	120	730	733+	1	52	Soft		50.00
28	NW. ¼	F. H. Moore	1888	2	151	715	719+	.37	53.5	do	151	100.00
28	W. side	M. E. McMullin [c]	1886	2	124	735	738	1.5	52			
28	Center	Mr. Brownell [d]	1894	2	148	730	732	.25	54	Soft	146	140.00
28	N. side	E. Davenport	1891	2	112	715	718+	1	52.5			
28	SW. ¼	R. O. Bradley [e]	1876	2	118	735	737	Weak.		Soft		
28	SW. ¼	O. W. Sangree [f]		2	118	735	737	Weak.		do		
28	SW. ¼	G. Kraut [g]	1890	2	104	695	697+	.5	53	do	102	140.00
28	SW. ¼	E. A. Pullem		2	104	695	696	.25	53	do	102	140.00
York		O. W. Sangree [h]		2	122	735	737	1	52.5		122	60.00
	Do	W. H. Culver	1882	2	115	736	737	Weak.	54	Soft	115	30.00
	Do	do		2	125	735	737	.37	53	do	125	50.00
	Do	I. N. Clark [i]		2	124	735	739	.37	53	do		45.00
	Do	Frank Haines		2	118	735	737	.5	52.5	do		
	Do	O. E. Fulkerson		2	120	733	739		53	do		
	Do	D. E. Davenport		2	148	735	737	.5	53	do		
	Do	Mr. Sill		2		736	738	.25	53	do		
	Do	J. L. Hobbs		2		700	702+	.5	53	do		
	Do	Daniel Rankin	1882	1.5	120	735	737	Weak.		do		
29	NE. ¼	Mr. Clarke	1888	2	130	715	717+	Weak.	53	do		50.00
29	NE. ¼	A. E. Montagne [j]	1898	2	125	735	737	.5	53	do	123	50.00
30	NE. ¼	T. Josenhaus	1894	2	127	735	737	.75	52	do		50.00
30	NE. ¼	do [k]	1894	2	178	740	738	1	52			100.00
30	SW. ¼	John Moody	1894		142	745	748	.5	54	Hard	142	
30	SW. ¼	Charles Ellis			130	735	740					
30	SW. ¼	E. Warner	1903									
31	Center	W. G. Roberts		1.5	96	720	722+	.75	52			
33	NW. ¼	R. G. Bird		2		695	698+	.5	56			

[a] Flow greater in wet seasons. The temperature is high on account of great exposure and small flow.
[b] Flowed 3 gallons a minute when made.
[c] Large amount of inflammable gas, probably from the underlying Devonian shales. It penetrated sand 3 feet, blue clay 121 feet, and struck water and gas in gravel.
[d] Limestone at bottom; flow may be from a thin bed of gravel above the rock. The well penetrated gravel 5 feet, blue clay 120 feet, gravel 2 feet, limestone 2 feet.
[e] When first opened flowed a full 2-inch stream, but is apparently clogged with sand.
[f] Soft enough to be used in boilers at factory.
[g] Blue clay 100 feet, hardpan and black gravel 2 feet, limestone 6 inches.
[h] Sand and gravel 4 feet, blue clay 110 feet, hardpan 1 foot, sand 1 foot, limestone 3 feet.
[i] Well when opened lowered head of other wells near it, and is now closed.
[j] Sand and gravel 20 feet, blue clay 100 feet, hardpan and gravel 2 feet, limestone 3 feet.
[k] Sandy loam 8 feet, blue clay 75 feet, quicksand 85 feet, and gravel 10 feet.

A strong flowing well was obtained many years ago in the Saline River Valley, in sec. 1, Saline Township, Washtenaw County, at a depth of 150 feet, when making a test boring for salt, but it is now plugged. This well suggests the possibility of extending the York district up the Saline Valley to Saline.

It is probable also that flows could be obtained along the Saline bottoms from York down to Milan, thus connecting the York district with the Milan-Cone district. Another line of connection with that district may be found along the valley of North Macon Creek. Outside of the valleys there seems no chance of obtaining flows in the tract lying between these two flowing-well districts, the water head in wells that have been made being a few feet below the surface.

HOLLOWAY DISTRICT.

This district lies along the southeastern border of the Belmore Beach, in the eastern part of Lenawee County. It is about 10 miles in length and from 2 to 4 miles in breadth, thus embracing an area of about 30 square miles lying between Britton and Lenawee Junction, with Holloway near the middle of its western border. The flowing wells occur in Ridgeway, Raisin, Blissfield, and Palmyra townships. Flows have not been obtained everywhere within this area. In

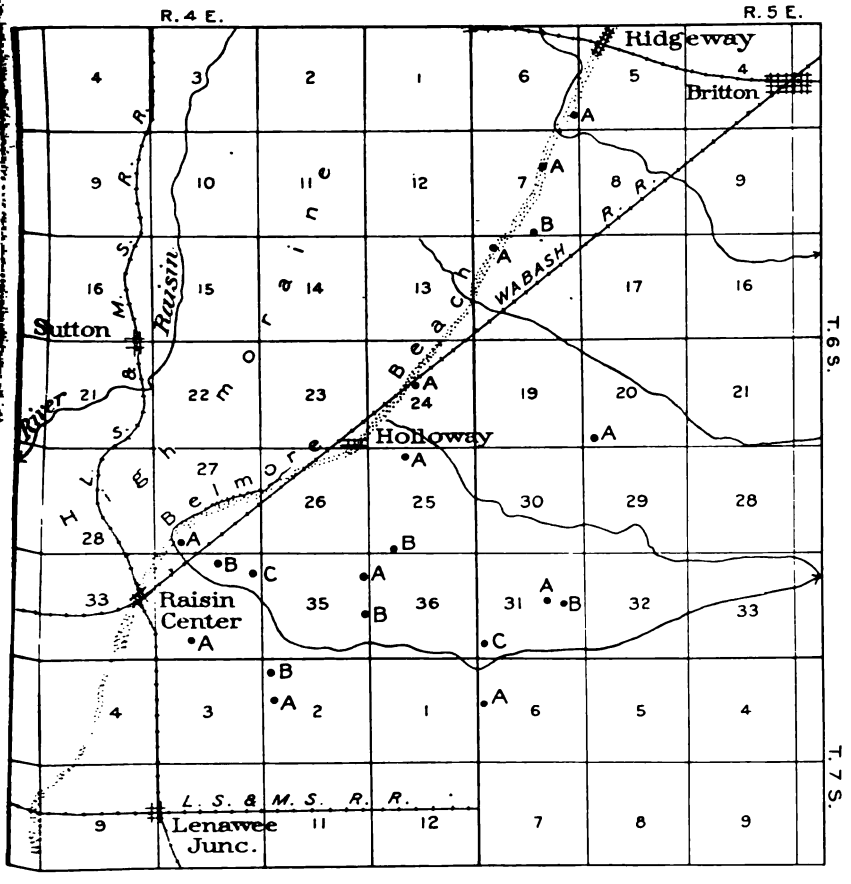


FIG. 6.—Map of Holloway flowing-well district, Lenawee County.

some cases the texture of the water-bearing beds is too fine to permit a copious discharge, while in others the head seems to be a little too low to give a flow. This district is practically a continuation of the York district, which extends from Washtenaw into northeastern Lenawee County, there being only a narrow interval near Ridgeway in which flows have not been obtained, and even there the failure seems to be largely due to the fine texture of the water bed. Further drilling may develop wells with good flow in this intervening territory

The data on wells in this district were collected chiefly by Jon A. Udden in 1904. The data on wells at Britton, however, had been previously collected by the present writer. No estimates of rate of flow nor observations of temperatures were made at Britton. The temperatures reported in the table are, in many cases, higher than the normal temperature of water from wells of these depths in this latitude, but are probably due to exposure of the pipes through the summer heat. The normal temperature is about 52° F. The altitudes are estimates made from comparison with altitudes of the old shore lines which traverse this district, except at Britton, where they are determined by comparison with the railway crossing, which is 701 feet, by levels run in making the Ann Arbor topographic sheet. The Britton wells are so much shallower than most of the other wells in this district that they should perhaps be considered a separate supply. In the village the wells are not deep enough to test conditions for a flow from depths corresponding to the average for the district, but on farms in the vicinity wells carried to the rock are found to have heads similar to those obtained at a shallow depth.

Below are given two partial analyses for the purpose of comparing the composition of the drift and rock waters at Britton. There has been much typhoid in the town, and the shallow drift waters should be looked upon with suspicion. The analyses were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of rock and drift waters at Britton.

[Parts per million.]

	1.	2.
Color	19	32
Iron (Fe)	Decided trace.	Decided trace.
Chlorine (Cl)	16.5	14
Carbon dioxide (CO_2)	66.83	83.9[illegible]
Sulphur trioxide (SO_3)	20	29
Hardness (as $CaCO_3$)	118.7	14[illegible]

S. J. Lewis, analyst. 1. Haight (rock), depth, 142 feet. 2. Vandeveer (drift); depth, 32 feet.

The altitude to which water will rise decreases rapidly in passing southeastward across this district, being about 740 feet in the vicinity of the Belmore beach and less than 700 feet 3 miles southeast.

The catchment area may be anywhere in the region northwest of these wells where water is readily absorbed.

As suggested above, the area is likely to be extended somewhat y sinking further wells. The present limits are outlined from the ew tests indicated in the table below:

Wells of Holloway flowing-well district.

Township S.	Range E.	Letter on fig. 8.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to.	Flow per minute.	Temperature.	Quality.
					In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*	
6	4	....	J. McIntyre [a]								
6	4	A	James Lane	1895	2	90	738	740	0.75	54	Hard.
6	4	B	—— Munch		2		710	713	.75	53	Medium.
6	4	A	W. Judson [b]	1899	2	47	740	743	.25	62	Do.
6	4	A	A. Hoxy		2		720	722	.25	53	
6	4	B	J. W. Ash [c]	1894	2	191	725	727	Weak.	65	Do.
6	4	C	John Rainey [d]	1895	2	116	720	722	.75	54	Medium; salt.
6	4	A	D. T. Mitchell [e]	1896	2	178	712	714			Do.
6	4	B	W. Miller	1894		110	700	703	.25	55	Do.
7	4	A	W. Damlow		2		715	719	.25	62	Medium.
7	4	B	H. P. Woodard	1895	2	134	715	718	.75	56	Do.
6	5	A	Henry Palmer [f]	1903	2	136	730	733	20	53	Hard.
6	5	A	H. Pocklington	1896	2		728	731	Weak.		Soft.
6	5	B	C. Pocklington	1899	2	135	726	729	.5	54	Do.
6	5	A	Thos. Florence [g]	1893	2	140	736	740	.75	54	Hard.
6	5	A	H. Schwab [h]			108	690	690			
Britton [i]			New schoolhouse	1903		45	697	698			
Do			Kishbaugh & Britton.	1903		26	697	698			
Do			John Winsley			28	700	698			
Do			Ann Exelby			45	697	698			
Do			Dutch Church parsonage.			45	697	698			
Do			Old schoolhouse			45	697	698			
Do			Britton Hotel			52	699	698			
31 6	5	A	W. Riddle [j]	1898	2	100	690	691	Weak.		Soft.
31 6	5	B	Mrs. Stahler [k]	1894	2	105	690	691	.75	54	Do.
31 6	5	C	J. Pangburn [l]	1899	2	108	690	696	Weak.	56	Do.
6 7	5	A	August Minster [m]		2	120	690	692	1.5	55	Soft; salt.

[a] No data.
[b] The Black seam called coal is struck at 32 feet, but glacial deposits underlie it; high temperature due to exposure of pipe.
[c] Water comes from a seam in blue clay at 97 feet; rock at 125 feet; stream too weak to give correct temperature at bottom.
[d] Water sulphurous; from limestone at 113 feet.
[e] Flow interrupted apparently by gas which comes up with the water. Well penetrated blue clay with occasional streaks of sand, and did not reach rock.
[f] When opened had a head of 740 feet; water strong in iron.
[g] Original head 744 feet and flow much stronger than now; shale at bottom.
[h] Rock at bottom.
[i] Several wells in Britton are bored and walled with large tile. Water is dipped from top of tile, which in some cases is carried high enough to prevent overflow.
[j] Does not flow above surface at present, but runs into a reservoir at a lower level. Clay, 60 feet; large sandstone (?) bowlder, 6 feet; quicksand, 40 feet; limestone at bottom.
[k] Limestone at bottom; gas; water has a salty taste.
[l] When first opened water was very hard. It rose 6 feet above surface; well now clogged with sand. Gravel, 3 feet; blue clay, 35 feet; gravel, 12 feet; quicksand, 2 feet; hardpan, 8 inches; gravel at bottom.
[m] Water lowered when Pangburn well was opened. Water has a sulphurous taste and deposits a white sediment in pipe; it is slightly salty, but not hard.

OGDEN TOWNSHIP (T. 8 S., R. 4 E.).

In Ogden Township, which is in the southern tier, flowing wells have been obtained in a small district extending northward from Ogden Center. About 20 wells overflowed when first made, but in 1904, when Mr. Udden canvassed the district, only seven were in use, the others having been filled with material from above. The wells are usually bored with a large auger and cased with tile, and

if properly cared for would in all probability have continued t flow. The first well to obtain a flow was that of F. Pence, ma about twenty-five years ago, but this has now become choked. Th flows now in operation are in secs. 9, 10, 16, and 17.

A. S. Burdsley has a flowing well at Ogden Center which di charges 1 gallon a minute and has a temperature of 53° F. Th water is slightly saline and sulphurous. It was used for a time in boiler at the mill, but is not used at present. It had a head of feet when made.

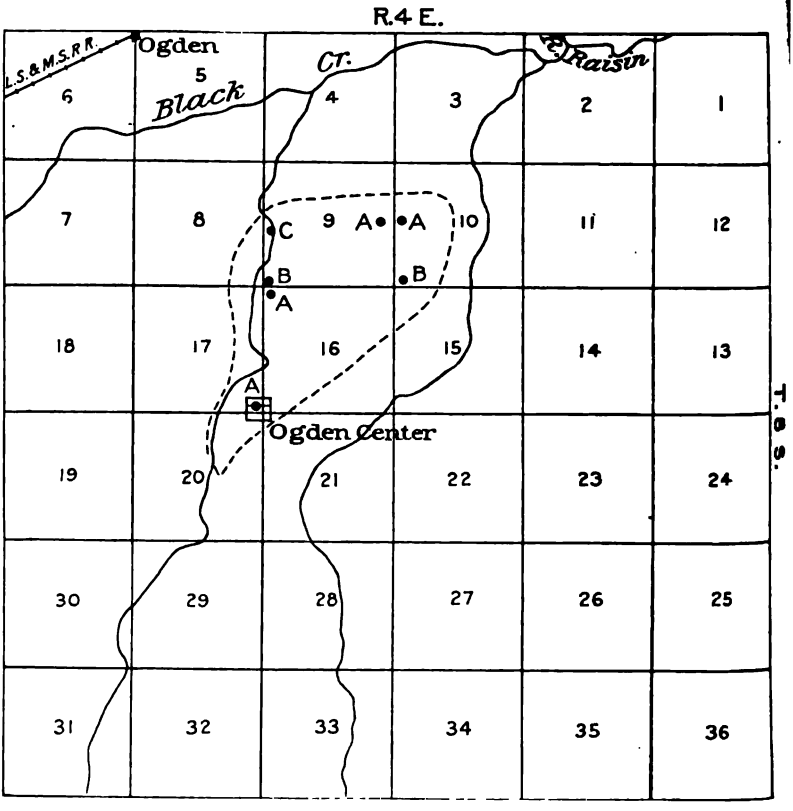


FIG. 7.—Flowing wells in Ogden Township, Lenawee County.

The well of Henry Case, in the west part of sec. 10, is 96 feet de and was made in 1884. A 12-inch tile extends to 45 feet and 7-inch thence to the bottom. The well now flows about 15 gallo a minute, or a quart every second. It flowed 12 quarts in ten se onds when made. The water is sulphurous and chalybeate, and h a temperature of 52.5° F. The well penetrated 10 feet of sand a 83 feet of blue clay to the water-bearing sand at the bottom. the southwest corner of sec. 10, on the Brockway farm, is a ve weak flow.

In the eastern part of sec. 9, on the Stauf farm, is a flow amounting to 1 gallon a minute. The well is 100 feet deep and was made in 1892. It has a 6-inch tile to about 45 feet and thence a 3-inch wooden penstock to bottom. On the western side of sec. 9, N. Henderson has a flowing well 80 feet deep, with slightly saline taste and medium hardness; temperature, 53° F. W. Emmons, in the southwest corner of sec. 10, has a flowing well 85 feet deep, with slightly saline water; temperature, 53° F. It has a 12-inch wooden casing. In the northwestern part of sec. 16 is the well of William Comley, 80 feet in depth, with 12-inch wooden casing for 40 feet and 8-inch casing thence to bottom. It was made in 1882. There is a slight discharge of gas with the water. Several wells of similar depth near these flowing wells have water 3 to 6 feet below the surface. On the plain between Ogden Center and Jasper water rises nearly to the surface in wells 90 to 200 feet in depth. In nearly all cases the water is slightly saline, and in several a small flow of gas has been noticed.

SAND CREEK.

At Sand Creek station, just east of the depot, is a well 103 feet deep, which barely flows at the altitude of the station, 779 feet above tide. It is owned by F. M. Smith, and was made in 1889. It discharges about 3 quarts a minute and has a temperature of 53° F. The well now has a half-inch pipe that extends 6 feet into the 1½-inch pipe. It is stated that the water will not flow from the larger pipe.

There is lower ground in the village of Sand Creek in which flows should be obtained, but as yet there has been no occasion to develop the field, shallow wells which supply the needs of the residents being easily obtained. Some families resort to the flowing well for drinking water.

It is probable that the catchment area is in the higher land northwest of the village.

MORENCI.

The village of Morenci is situated on Tiffin River (also called Bean Creek) near the State line of Michigan and Ohio. Data on the flowing wells of this village were collected and tabulated by Jon A. Udden. It will be observed that wells have been in operation since 1887 which still have a good flow. The wells are all 2-inch, but differ widely in rate of flow, ranging from 32 gallons a minute down to a mere trickle. The strongest flows are in the eastern part of the village. The certainty of obtaining a flow within the limits of this district is such that drillers need take no risk and can afford to make wells at a lower price than where a risk is involved. This explains the low cost of $15 to $20 for certain wells 70 to 80 feet in depth, the ordinary charge per foot, including pipe, in a 2-inch well being

75 cents. In some cases a driller is paid about $6 a day to mak the well, instead of receiving pay by the foot. The 2-inch casin used costs ordinarily 20 cents a foot. The wells have been made b two drillers, F. Paine and B. Thomas.

The water has considerable iron, and brown algæ are developed i many of the pools or troughs into which it discharges. The wat appears to be of medium hardness and is often used without th addition of softening compounds.

The wells show only occasional instances of interference, and th field admits of still fuller development and may be extended som distance farther both up and down the valley of Tiffin River. In th central part of the village the altitude is 3 to 4 feet above the hea reached by the wells. Flows are obtained on each side on lowe ground.

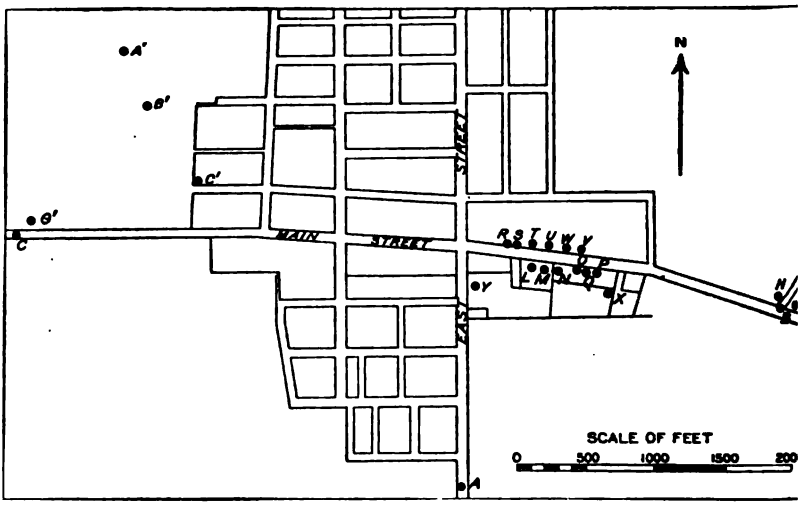


FIG. 8.—Plat of Morenci, Mich., showing flowing wells.

The catchment area is probably in the higher land to the nor west of Morenci.

At the time of Mr. Udden's visit to Morenci, in July, 1904, th was a strong sentiment in favor of putting in waterworks, and it w proposed to drill about five wells to supply the plant.

The following partial analyses are results of the examination two characteristic waters of flowing wells near Morenci. The we however, do not appear in Mr. Udden's list, and therefore th analyses can not be compared with the notes collected by him. T data are furnished by M. O. Leighton, of the United States Geologi Survey.

Partial analyses of waters from flowing wells near Morenci.

[Parts per million.]

	1.	2.
Color	10	19
Iron (Fe)	1.5	2.5
Chlorine (Cl)	11.5	4
Carbon dioxide (CO_2)	115.2	121.8
Sulphur trioxide (SO_3)	20	.29?
Hardness (as $CaCO_3$)	139+	139+

1. Crabb well; depth, 104 feet. 2. Young well; depth, 75 feet.

Wells at Morenci.

Letter on fig. 8.	Owner.	When made.	Cost.	Depth.	Elevation.	Water rises to — [a]	Flow per minute.	Temperature.	Quality.
				Feet.	*Feet.*	*Feet.*	*Galls.*	*° F.*	
A	Town of Morenci	1889	$35	70	755	758	4	53	Medium.
B	do	1889	30	75	755	758	4	52.8	Do.
C	do	1889	35	75	735	736	1	53	Do.
D	A. L. Sebering [b]	1903	23	76	755	767	32	52.5	Soft.
E	R. P. Boody [c]	1887	30	72	755	767 756	7	54	Do.
F	Geo. Webber [d]	1904	30	74	755	756	Weak.		Do.
G	S. B. Miller [e]	1895	15	73	757	760	1	53	Medium.
H	J. H. Eldridge [f]	1891	18	70	757	769 759	1	53	Soft.
I	Louis Phillipar	1888	25	78	757	760	1	53	Medium.
J	do	1889	25	78	757	760	1	53	Do.
K	F. Paine [g]	1887	14	78			1	53	Hard.
L	Mrs. Hass [h]	1890	33	72	760	762	.75	53	Medium.
M	J. Bailey	1891	43	90	758	770 762	1	53	Soft.
N	Mr. Carr [i]	1904	19	70	757	761	8	53	Do.
O	S. T. Snow	1889		78	755	757	1	53	Do.
P	Ed. Wells				755	757	1	53	Do.
Q	L. Woolcott [j]			150	756	758	1	53	Do.
R	W. S. Mason			78	758	758	.75	53	Do.
S	O. Onweller				758	758½	.75	53	Do.
T	Mrs. Aberling [k]	1900		78	758	758½	1	53	Do.
U	Mr. Morgan	1889	35	78	758	760	1	53	Do.
V	F. Kennedy	1888	35	78	755	758	1	53	Do.
W	T. Warren [l]	1888	35	78	757	760	2	52.5	Do.
X	J. Bailey	1890	35	90	755	758	1	53	Do.
Y	Mr. De Merrits	1888	35	90	755	756	1	53	Do.
A	Kellogg & Buck	1900	35	54	755	758	2	53	Do.
B	Burn Lee [m]	1902	35	64	756	758	2	53	Do.
C	F. Nocso [n]	1891	50	108	755	758	10	53	Do.
D	S. S. Beatty [o]	1894	14	70	756	758	1	53	Do.
E	S. A. Schofield [p]	1896	18	100	755	757	1	53	Do.
F	W. S. Scott [q]	1892	35	125	755	758	1	53	Do.
G	C. C. Wakefield [r]	1895	36	104	755	757	1	53	Do.

[a] Where two altitudes are given, the first refers to the original head.

[b] Gravel 25 feet, blue clay 50 feet, hardpan 4 inches, sand at bottom. Head 12 feet; flow now reduced to 8 gallons a minute.

[c] Sand and gravel 20 feet, blue clay 51 feet, hardpan 1 foot, sand at bottom. Original head 11.8 feet. First fountain in this section.

[d] This is the east limit of flows.

[e] Iron present; algæ brown; clogged by sand.

[f] Head 12 feet when opened; now clogged by sand. Sand and gravel 65 feet, blue clay 4 feet, gravel 1 foot.

[g] Sand and gravel 22 feet blue clay 56 feet, hardpan, sand.

[h] Carr's & Sebering's wells have lowered the head of the Hass well about 16 inches.

[i] Sand 9 feet, blue clay 61 feet, hardpan 18 feet, gravel at bottom.

[j] Sand and gravel 5 feet, blue clay 60 feet, hardpan with pebbles 5 feet, fine sand 75 feet.

[k] Sand and gravel 9 feet, clay 60 feet, hardpan 3 feet, gravel at bottom.

[l] Sebering's well has lowered head slightly.

[m] Used for boilers and brickmaking.

[n] Used in creamery for boiler, and also in manufacture of butter and condensed cream.

[o] Sand 4 feet, blue clay 65 feet, gravel 1 foot.

[p] Sand and gravel 15 feet, blue clay 85 feet, gravel 1 foot.

[q] Sand 6 feet, blue clay 95 feet, pebbly hardpan 24 feet, gravel.

[r] Sand 12 feet, blue clay 40 feet, dark-brown and very pebbly hardpan 6 feet, dark-blue clay 56 feet. Weak flow at 60 feet; a good flow at 104 feet.

MEDINA.

In the eastern part of the village of Medina, in the valley of Tiffin River, is a single flowing well on the Seeley property. It is 20 feet in depth, and flows one-half gallon a minute, with a temperature of 53° F. The water is of medium hardness. The well has been in operation since 1900. Other flowing wells may be obtained along the creek bottom, but the head seems to be insufficient to secure a flow on the bluff or bordering uplands.

ROLLIN TOWNSHIP.

East of the village of Rollin, in Rollin Township, Lenawee County (T. 6 S., R. 1 E.), is a small flowing-well district in a sag between morainic ridges. In 1904 there were a few wells located in secs. 22,

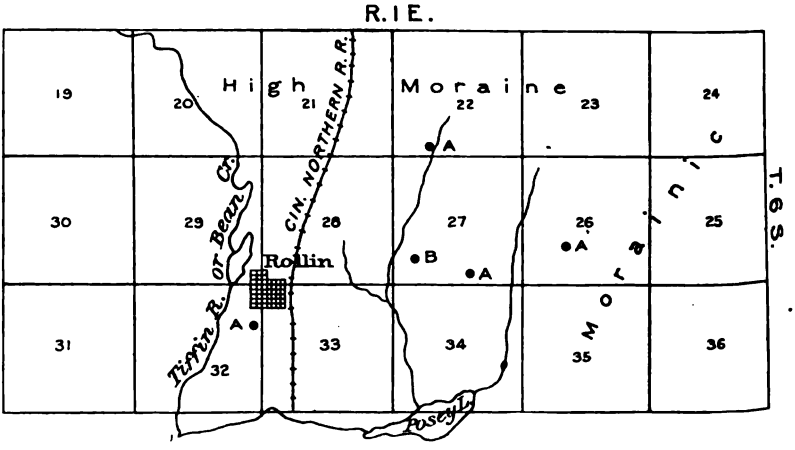


FIG. 9.—Map of southern part of Rollin Township, Lenawee County, showing distribution of flowing wells.

26, 27, or 32. They are so widely scattered that it is uncertain whether they occupy independent pools or form a single pool. The data were collected by Mr. Udden, and if his determinations are correct the wells display a difference of 65 feet in altitude, the shallowest being on the highest ground. The wells are probably supplied from an elevated catchment area to the west and north. How much the area may be extended is difficult to forecast. The wells are strongly chalybeate. In some cases they appear to have a decidedly stronger flow just before a storm. The deeper wells obtain water from gravel under a heavy bed of blue clay. The Foster well, in sec. 27, which is only 27 feet deep, was dug 20 feet and bricked up, and then lowered 7 feet by drilling in the bottom.

Wells at Rollin.

Letter on fig. 9.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Cost.	Flow per minute.	Temperature.	Quality.
				In.	*Feet.*	*Feet.*	*Feet.*		*Galls.*	*° F.*	
A.	32	H. J. Snyder	1900	2	96	985	986	$100	1	52.8	Medium.
A.	27	J. B. Foster	1880	36	27	1,050	1,052	.....	1	54	Hard.
B.	27	D. H. Allen	.....	2	.....	1,022	1,023	.....	1	54	Do.
A.	26	M. Childs	1902	2	90	1,020	1,021	80	1	.....	Do.
A.	22	F. Seeley [a]	.....	.....	.....	.....	.....	.....	.....	.....	

[a] No data.

HUDSON TOWNSHIP.

There is a single flowing well on the farm of Mr. Buck, 1½ miles east of Hudson, in the western part of sec. 16, Hudson Township (T. 7 S., R. 1 E.). It is only 16 feet in depth and has a weak flow from a 1½-inch pipe. The water is from sand under clay. This well is on the western slope of a moraine that furnishes the probable catchment area, and it is possible that other flows may be obtained near by, especially if made in depressions.

TIPTON DISTRICT.

This district leads both northeast and southwest from the village of Tipton, in northern Lenawee County, and at the southwest may

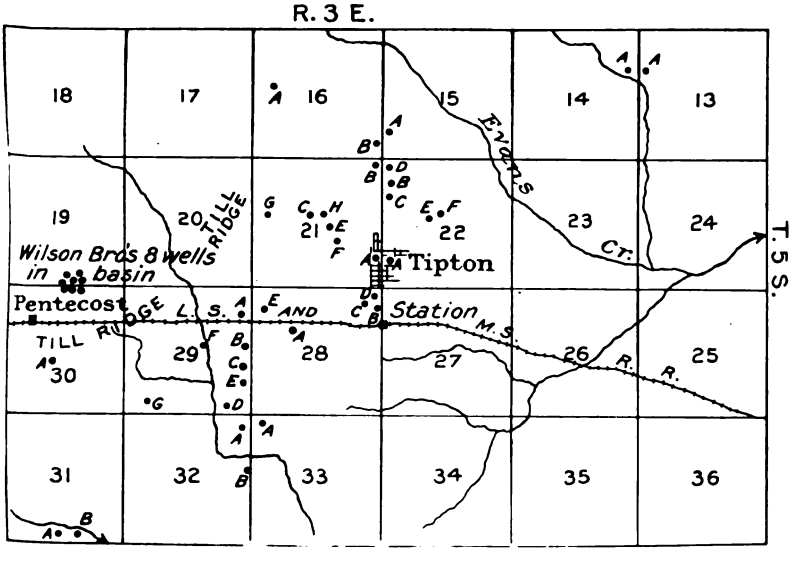


FIG. 10.—Flowing wells near Tipton, Lenawee County.

find continuation in the scattered flows along Wolf Creek Valley. The district is about 1½ miles wide and 10 miles long if the Wolf Creek wells are included. The Tipton district proper lies entirely in Franklin Township (T. 5 S., R. 3 E.), and runs from sec. 13 southwest to sec. 31. West of it is a small isolated group of flowing wells

in a basin near the line of secs. 19 and 30, Franklin Township, which is separated from the main district by a till ridge too high to permit flows. There are also numerous knolls within the district on which flows can scarcely be expected. In the flowing-well district there is a perceptible southeastward descent, the altitude of wells on the northwest border being 20 to 30 feet higher than that of those on the southeast. The altitude of the water declines more rapidly southeastward than this somewhat rapid descent, for wells east of the flowing wells lack a few feet of rising to the surface.

In the village of Tipton flowing wells can be obtained only in sag a few feet below the general level, while wells east of the village, on ground lower than these, do not flow even when driven to depths o 100 feet or more. The wells usually pass through a clayey till, yel low at top and blue from a depth of 10 feet onward. The water i found in thin beds of gravel and sand in the till. These beds appea to occur at various levels, so that neighboring wells may differ mark edly in depth.

The water is hard and carries so much iron that it coats vesse rapidly and soon rusts tinware. In some wells the iron is percept ble to the taste. The writer listed about 20 wells in this distric north and east of Tipton in 1899, some of which are not included i the list prepared by Mr. Udden. As the writer's examination wa incidental to other investigations, data on the wells are meage Two of these wells are on a tributary of Evans Creek along the line of secs. 13 and 14, and are about 2 miles from any reported b Udden. Possibly the intervening territory is too elevated to pe mit of flows. The wells referred to are only 20 to 25 feet deep- much shallower than the average depth of wells in this distric There are two shallow flowing wells, not noted by Udden, near th center of sec. 22 on the farm of Mr. Whelan, the depth of which i even less than of those in secs. 13 and 14, being but 22 feet. Th altitude, however, is about 30 feet lower than at a flowing well, 5 feet deep, at Mr. Whelan's residence.

The flowing wells in the isolated basin on the line of secs. 19 an 30 are on ground about 20 feet lower than Pentecost station, whi is at the south edge of the basin. The wells, 8 in number, are the border of a peat bog used for a celery farm, and range in dep from 40 to 60 feet. They are controlled, and the water is distribut as needed. They are said to fill the 2-inch pipes and discharge ma gallons a minute. The head, however, is not great, being estimat at 10 feet or less. Wells and basins of this kind may have the catchment areas on the bordering high land.

The catchment area for the Tipton district probably lies along i northwest border, though some of the supply may be from still high land to the west and north.

Wells in Tipton flowing-well district.

er 0.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.
				In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*°F.*	
...	13	Loren Taylor	.....	.....	25	−860	.....	.....	.....	
...	14	Smith Munger	.....	.....	25	−860	.....	.....	.....	
...	15	E. J. Whelan	1890	2	.....	−902	903	1	53	
...	16	F. M. Dibble [a]	1897	1.5	48	915	917	2	51	Hard.
...	16	A. Morseman	.....	2	40	905	907	2	52	Hard; iron.
...	21	John Conlin	.....	2	40	900	900.2	.....	.....	Hard; sulphur, iron.
...	21	Thomas Conlin	.....	2	66	904	906	1	53	
...	21	Orville Kemp	1888	2	.....	907	910	1.5	54	Hard.
...	21	B. F. Norcross	.....	2	.....	904	906	.5	52	Hard; iron, sulphur.
...	21	.....do	.....	2	80	907	911	5	52	Do.
...	21	W. A. Beebe	.....	2	.....	905	906	1	53	Hard; iron.
...	21	W. E. Camburn	.....	2	.....	910	911	1.5	53	Do.
...	22	John Conlin [b]	1880	1.5	40	899	900	Weak.	.....	Hard.
...	22	Martin Whelan	1891	2	51	905	907	4	53	
...	22	.....do	1891	2	64	905	907	1	53	
...	22	School district No. 3.	1890	2	70	905	907	1	53	Hard; iron.
..	22	Martin Whelan	.....	.....	22	875	880	.....	.....	
...	28	Charles Lewis	.....	2	.....	895	898	3	50	Hard; iron, sulphur.
...	28	.....do	.....	1.5	.....	895	897	.75	52	Do.
..	28	.....do	.....	1.5	.....	895	898	8	52	Hard; strong in iron.
..	28	.....do	.....	1.5	.....	898	899	1	53	Hard.
..	28	John Buttrick	.....	2	62	905	907	.75	52	Hard; iron.
..	29	R. Kerr	.....	2	.....	905	907	1.5	53	Do.
..	29	John Cook	.....	2	70	900	902	20	52	Hard.
..	29	W. S. Pentecost	1889	2	75	916	917	15	52	Do.
..	29	A. Preston [c]	.....	2	42	905	908	20	52	Do.
..	29	W. S. Pentecost [d]	.....	2	40	903	905	2	52	Do.
..	29	Lilly & Strong	.....	2	70	915	918	2	52	Hard; iron.
..	29	R. Warren [e]	.....	2	.....	912	914	2	52	Do.
..	30	C. Ridgebridger	.....	2	.....	912	914	1	51	Do.
..	32	C. B. Beebe [f]	.....	.....	.....	905	907	.....	51	Hard.
..	32	F. E. Derby	.....	2	.....	895	897	5	52	Do.
..	33	Charles Kemp	.....	2	.....	905	906	2	51	Hard; iron.

ur other flows have been in use but are now plugged. Black muck 24 feet, gravel 1 foot, blue clay hardpan 6 inches.
ow decreased on account of sand and gravel filling pipe. First well in village of Tipton.
ree-fourths inch reducer used; head originally 932 feet.
eds sand pumping, flow has decreased.
iginal head, 930 feet, weak flow at 27 feet; one-half inch reducer used.
s had 6 wells.

WOLF CREEK DISTRICT (TPS. 6 S., RS. 2 AND 3 E).

here is a narrow strip along Wolf Creek Valley, in northeastern ie and western Adrian townships, in the vicinity of Wolf Creek -office, in which flowing wells have been obtained. The head is sufficient to give a flow except in ground 25 feet or less above creek. Wells on higher ground show a rise corresponding to that ie flowing wells, so that water is frequently very near the surface. ; district may, as indicated in the discussion of the Tipton district, continuation of that district. Data on these flowing wells were ained by the writer in 1899, and it is not known whether other ing wells have since been obtained.

. E. Marshall has a well at Wolf Creek village, 94 feet deep, which etrated till 50 feet and then sand to bottom. There may have n a crust of hardpan above the water. The water rises fully 10 above the surface, and the well is about 15 feet above the stream.

A well at L. B. Knoll's store at Wolf Creek, 78 feet deep, flows with a head of about 10 feet. This well has till at the same level as the sand in the Marshall well.

Richmond Ross has a flowing well, 81 feet in depth, a mile south of Wolf Creek, in sec. 7, Adrian Township.

On the Wilcox farm, in sec. 13, Rome Township, 1½ miles south of Wolf Creek, is a strong flowing well about 40 feet deep. It is a dug well, into which the water came so rapidly that it was not walled, but was filled with bowlders.

Across the road from the strong well on the Wilcox farm, on the farm of Henry Thomas, is a weak-flowing well, thought to be 76 feet deep.

There is also a shallow and weak-flowing well one-half mile north of Wolf Creek, in sec. 1, Rome Township.

There were, in 1899, two weak-flowing wells, 70 feet deep, 1½ miles northeast of Wolf Creek post-office, in sec. 31, Franklin Township, on the farm of Cornelius Derby.

WATER SUPPLIES OF HILLSDALE COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Hillsdale is the most elevated county in the southern part of the State, its altitude ranging from about 830 feet in the southeast corner to 1,284 feet at "Bunday Hill," a prominent gravel hill near the north border. This county includes the sources of Grand, Kalamazoo, and St. Joseph rivers, tributary to Lake Michigan, and also of Raisin River and St. Joseph, of the Maumee tributary to Lake Erie. A prominent morainic system traverses it from northeast to southwest, constituting the divide between the Lake Michigan and Lake Erie drainages. Parallel with this on the southeast are other moraines at lower altitudes, and below these moraines are sags and narrow plains. The northwestern part of the county is broken by sandstone ridges, which in some cases are only thinly veneered with glacial deposits. In the sandstone ridges, and also in the loose-textured drift that make up the bulk of the morainic ridges, the ground-water table is usually at considerable depth, so that wells 75 to 125 feet in depth are not rare, while a few extend 200 feet. On the plains and in depressions among the ridges the distance to water is usually but a few feet. There are, however, places in which a compact clayey till underlies the plains, and there it may be necessary to go to considerable depth to find a good well. Flowing wells have been found in valleys or deep depressions at several points, and may perhaps be obtained at other points. They are usually

ıe drift, but near Reading they are obtained from the rock. tion to these valley districts there is a district covering sev- ıare miles in Ransom and Amboy townships, where flowing ıve been obtained.

WATERWORKS.

e are but three towns in the county in which public water s have been developed: Hillsdale, Jonesville, and Reading.

HILLSDALE.

public water supply of Hillsdale is drawn from Bawbese Lake, lies in the valley of a tributary of St. Joseph River, about a ›ove Hillsdale. The waterworks plant was built in 1886 at a $75,000, and has 12 miles of mains, 81 hydrants, and 1,180 There are two Block pumps with a capacity of 2,000,000

JONESVILLE.

village, which stands in the St. Joseph Valley, obtains its from three tubular wells, two of which are in gravel at about and one in rock at 80 feet. It enters rock at about 60 feet. ıping, the wells yield about 500,000 gallons a day.

following is a partial analysis of the village supply at Jones- ırnished by M. O. Leighton, of the United States Geological . The supplies are from three wells, two in gravel and one ·ock, so that the sample represents a mixture of the three.

Partial analysis of well water at Jonesville.

	Parts per million.		Parts per million.
.....	19.	Carbon dioxide (CO_2).....	110.80
.....	2.	Sulphur trioxide (SO_3).....	29
(Cl).....	1.5	Hardness (as $CaCO_3$).....	139+

›wis, analyst. Depth, 56 feet.

READING.

village derives its supply from 4 tubular wells 58 to 65 feet h, which enter rock at about 28 to 30 feet. The water stands ›elow the surface. The wells are on low ground outside the The plant was installed in 1900 at a cost of $22,500, and miles of main, 38 hydrants, and 165 taps.

w is given a partial analysis of the public supply at Reading. ›tained from shallow wells in the lower part of the village. ıta are furnished by M. O. Leighton, of the United States ical Survey.

Partial analysis of well water at Reading.

	Parts per million.		Parts per million.
Color	19	Carbon dioxide (CO_2)	106.76
Iron (Fe)	.8	Sulphur trioxide (SO_3)	25
Chlorine (Cl)	4	Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 56 feet.

Private wells 15 to 30 feet deep are still in common use.

MISCELLANEOUS VILLAGE SUPPLIES.

At Cambria, which is located about 6 miles southwest of Hillsdale, in the valley of a tributary of the St. Joseph of the Maumee, wells are all shallow, ranging from 8 to 35 feet in depth. The best supplies are at about 30 feet.

At Litchfield, in the valley of St. Joseph River, in the northwestern part of the county, many wells are drilled into rock and obtain strong supplies at 45 to 60 feet. The deepest wells are about 100 feet. Some wells obtain water from the drift at 10 to 15 feet.

At Mosherville, in Kalamazoo River Valley, in the northern part of the county, wells are generally 20 to 30 feet deep. A few in the vicinity are drilled in rock to depths of 100 feet or more.

At North Adams, in the north-central part of the county, well are usually 40 to 80 feet, though a few are shallower. Rock is entere at about 80 feet, but supplies are usually found in gravel above th rock. Fire protection is provided in a reservoir supplied from well

In the vicinity of Pittsfield some wells are 150 to 245 feet dee and a depth of 150 feet is common. In some the water stands 1C to 130 feet below the surface.

At Waldron wells are usually about 30 feet deep, but the large supplies are from 90 to 120 feet.

FLOWING WELLS.

RANSOM TOWNSHIP.

This district embraces half a dozen shallow flowing wells scattere over three sections in Ransom Township south of Ransom Cente and only 2 or 3 miles from the Ohio-Michigan State line. (See fig 11.) They are on a till plain sloping southeastward, the catchmen area probably being on higher land immediately northwest. Th data on these wells were collected and arranged by Jon A. Udden:

Wells near Ransom, Hillsdale County (T. 8 S., R. 2 W.).

Letter on fig. 11.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.
				Inches.	*Feet.*	*Feet.*	*Galls.*	°*F.*	
A	27	Charles Moore	1900	4	26	+1.5	2.5	50	Hard, iron.
B	27	Frank Day	1900	4	20	+ .83	1.5	51	Do.
C	27	J. Gear[a]	1883	4	27	+8	4	50	Do.
A	28	Isaac Ely		4	22	+1.25	1.5	51	Do.
B	28	M. Welder		4	22		1.5	51	Do.
A	33	J. C. Gear	1883	4	27	+8	4	50	Do.
B	33	(b)							

[a] When made this well flowed 32 gallons a minute; it now has a ½-inch reducer. The water in this and other wells in this group is from the gravel below the till.
[b] No data.

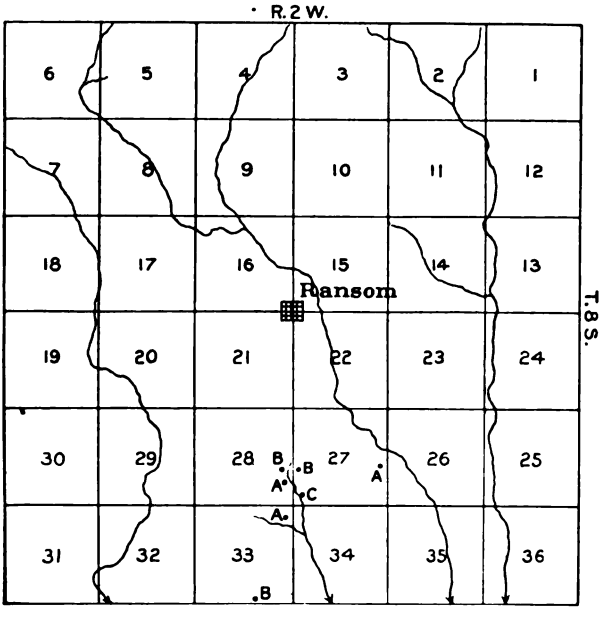


FIG. 11.—Flowing wells near Ransom, Hillsdale County.

JEROME.

At the village of Jerome, in northeastern Hillsdale County, in a basin at the head of Raisin River, is a group of shallow flowing wells. They are obtained only on low ground near the stream. The well at the Jerome Creamery is 35 feet deep and had a head of 8 feet in 1901. Mr. Udden visited it in 1904 and found the head only 6 feet. The well is 3-inch, and in 1901 discharged 5 gallons a minute. In 1904 its flow, as determined by Udden, was 7 gallons. The temperature in April, 1901, was 53° F. The well was through blue clay most of its depth, and obtained water in gravel. The water is slightly chalybeate.

At the public school there was a very weak well in 1901, but Udden reports a well drilled there in 1904 that had a flow of 3 gallons a

minute. It is on ground 5 feet higher than the creamery well, and its depth is correspondingly greater, being 40 feet. The Cincinnati Northern Railroad had a well at its station in Jerome in 1901 that flowed vigorously a few feet below the surface into a shallow dug well. The well is about 60 feet deep. H. S. Walworth had a flowing well at his barn that discharged in 1901 into a dug well 4 feet below the surface. Udden reports a well 40 feet deep made by Mr. Walworth in 1904 that has a head of 1 foot and a discharge of 2 gallons a minute.

Another flowing well reported by Udden is that of J. Chandler, which is 40 feet deep, has a head of 1 foot, and discharges 2½ gallons a minute.

Wells at Jerome.

Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Quality.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	
Creamery well	1900	3	40?	1,107	1,113	7	Hard, iron.
Public school	1904	2.5	40	1,112	1,113	3	Do.
H. S. Walworth	1904	2.5	40	1,110	1,111	2	Do.
J. Chandler	.....	.....	40	1,109	1,110	2.5	Do.

MOSCOW TOWNSHIP (T. 5 S., R. 2 W.).

A single flowing well was in operation in 1901 on the farm of R. O. Showday, about 1½ miles south of Moscow, in Moscow Township, in Kalamazoo River Valley. No further data were obtained. This valley is much lower than bordering uplands, and may prove to have conditions favorable for flows along its course down to Moscow.

WHEATLAND TOWNSHIP (T. 6 S., R. 1 W.).

A flowing well on the farm of H. E. Williams in sec. 16, Wheatland Township, is reported by W. F. Cooper to have a depth of 50 feet, a head of 15 feet, and a temperature of 52° F. The altitude is about 1,100 feet, or a little lower than the general elevation of the region.

ALLEN TOWNSHIP (T. 6 S., R. 4 W.).

A well on the farm of Walter Jones, in Allen Township (sec. 34), is reported by W. F. Cooper to flow in the spring and through wet seasons but usually to fall to about 5 feet below the surface in dry seasons. The well is 55 feet deep, and the altitude, as determined by Mr. Cooper, is 1,113 feet. Other wells in that vicinity vary several feet in accord with the rainfall, but no others ever flow.

CAMDEN.

There is a single flowing well in the valley of a tributary of St. Joseph River about ¼ mile northeast of Camden village, on the property of B. R. Alword, in sec. 22, T. 8 S., R. 4 W., or about 3 miles east of the northeast corner of the State of Indiana. It was made in 1892, is 120 feet deep and 3 inches in diameter, and obtains its supply from gravel. It flows about 6 gallons a minute, and the water is reported by the owner to have a temperature of only 49° F. It is used in a creamery and cheese factory for cooling purposes as well as by residents for drinking. The water contains considerable iron and is hard.

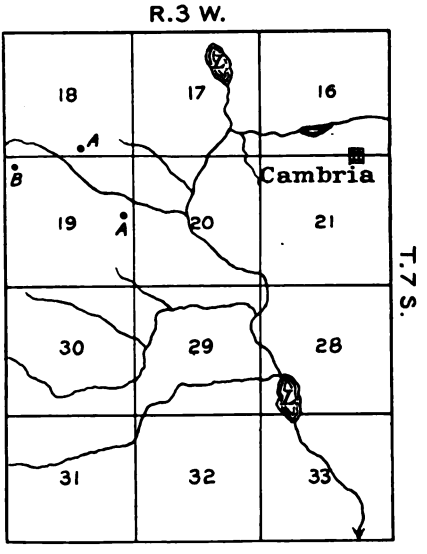


FIG. 12.—Flowing wells (from rock) near Cambria, Hillsdale County.

CAMBRIA TOWNSHIP.

In the western part of Cambria Township (T. 7 S., R. 3 W.) are three flowing wells from rock. They are along a valley considerably below the general level of the region. The water is softer than that from neighboring wells that terminate in the glacial deposits. The wells are cased to the rock, and in some instances a short distance into the shale, which is the upper rock. Water is found in sandstone.

The catchment area is not easily located where wells are so deep seated, and is especially hard to ascertain when the water has a shale cover. It is probable, however, that this cover has been eroded in places, allowing waters from the drift to have access to the sandstone. The tabulated data are from notes by W. F. Cooper and Jon A. Udden.

Wells near Cambria.

Letter on fig. 12.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Length of casing.	Temperature.
				Inches.	*Feet.*	*Feet.*	*Gallons.*	*Feet.*	° *F.*
A	18	Arthur Lane	1902	2	90	13	2.5	65	51
A	19	U. Woodring	1904	2	125	14	5	.....	51
B	19	E. Mead[a]	1900	2	104	2	2.5	85	51

[a] Sand and gravel, 20 feet; blue clay, 57 feet; shale, 27 feet; water probably at top of sandstone. The other wells each entered sandstone a few feet, and the drift in them is largely sand and gravel.

WATER SUPPLIES OF BRANCH COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Branch County is in the south tier of counties, about midwa between Lake Erie and Lake Michigan, its county seat being Col water. St. Joseph River crosses the northwestern part and i tributaries drain the entire county. A broad gravel plain along tl river and others along the tributaries together cover fully one-thi of the surface, the remainder being a till tract in which moraines a not conspicuous, much of it being a gently undulating plain.

So far as ascertained no flowing wells occur in the county. Tl wells are generally too shallow, however, to test the chances of a flo Water in abundance is ordinarily found at depths of 20 to 40 feet, even less on the gravel plains. On the moraines and till plains, als wells are shallow and usually dug. Near Sherwood and Union Ci there are a few driven wells 75 feet to 100 feet in depth. The driv wells are usually on the high points and show but little rise of wat

WATERWORKS.

COLDWATER.

There are public water supplies at Coldwater, Quincy, and Uni City, all from tubular wells of moderate depth. Those at the Co water waterworks are 50 feet deep and 6 inches in diameter. Tl will yield by heavy pumping 1,500,000 gallons a day, which is maximum consumption. The average consumption is about 500,(gallons a day.

QUINCY.

The public supply at Quincy is from a 6-inch well 30 feet deep which water is found at 15 feet and at 35 to 38 feet. The well yield by heavy pumping 20,000 gallons an hour. Below is give partial analysis of the water from this well, the data being furnisl by M. O. Leighton, of the United States Geological Survey. water is very hard and not entirely safe for drinking purpc because of liability to contamination.

Partial analysis of well water at Quincy.

	Parts per million.		Par per mi
Color	15	Carbon dioxide (CO_2)	11
Iron (Fe)	Slight trace.	Sulphur trioxide (SO_3)	2
Chlorine (Cl)	2.75		

S. J. Lewis, analyst. Depth, 36 feet.

UNION CITY.

Union City is supplied from a group of nine drilled wells, but little information could be obtained concerning them.

MISCELLANEOUS VILLAGE SUPPLIES.

The table below gives data furnished by residents to whom water-supply blanks were submitted:

Village supplies in Branch County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Batavia	100	945	Open and driven wells.	+25	20	25	25	25	−15	Small.
Bronson	1,176	926	do		12	40	30	30		
Butler		1,015	Dug wells	30	20	40	30	30		
California			do				30	30		
Coldwater	6,216	982	Driven wells	115	30	50	50	50		
Girard		900	Dug and driven wells.		18	30	30	30		
Kinderhook			Dug wells		18	40	25	25		
Quincy	1,563	1,026	Driven wells	30	15	35	20	30	−12	
Sherwood	366	875	Shallow wells, dug or driven.		15	20	20			

WATER SUPPLIES OF ST. JOSEPH COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

St. Joseph County is very largely occupied by gravel plains on which water is easily obtained at depths of 20 to 40 feet or less. It has a morainic tract along its western edge and another leading from Centerville southeastward on which the wells vary in depth from 20 to 100 feet or more. There also is a till tract in the northeastern part of the county where wells are of various depths up to 100 feet, a common depth being 70 feet.

Flowing wells have been obtained on the border of Klingers Lake in the southern part of the county and in St. Joseph Valley at Three Rivers. It is probable that flows would be obtained at other points along St. Joseph River if deep wells were sunk.

FLOWING WELLS.

KLINGERS LAKE.

A large number of excellent flows have been obtained on the border of Klingers Lake, some yielding as high as 15 gallons a minute. The wells are mainly 40 to 50 feet or less in depth, but some are 75 to 80 feet. The water will rise to a height of about 20 feet above lake

level. The temperature is quite uniformly 53° F. Resorts which have been built up on the shore are known as "Mound Springs" and "Mineral Springs." Nearly all the cottages have wells, which, when fully developed in fountains and grottoes, will form a very attractive feature of the resorts.

Below is given a partial analysis of a representative sample from a flowing well near Klingers Lake, together with a sample of lake water from the same locality. The data were furnished by M. O. Leighton of the United States Geological Survey.

Partial analyses of well and lake water at Klingers Lake.

[Parts per million.]

	1.	2.
Color	19	10
Iron (Fe)	2.5	Slight trace
Chlorine (Cl)	1.5	1.5
Carbon dioxide (CO_2)	100.56	59.1
Sulphur trioxide (SO_3)	15	15
Hardness (as $CaCO_3$)	.....	118.7

S. J. Lewis, analyst. 1. George Corson; depth 47 feet. 2. Lake.

The basin in which Klingers Lake stands is so much lower than bordering tracts that the latter may easily furnish the head displayed in these wells. Whether the supply is from a moraine north of the wells or from the gravelly plain forming an outwash east and south of the lake is not determined.

WATERWORKS.

THREE RIVERS.

The flowing wells at Three Rivers constitute the supply for the waterworks. There are nine 6-inch wells 75 to 100 feet in depth obtaining water in sand, but thought to have reached shale at the bottom of the deepest. The supply is ample for the present needs of the town. The water will rise only a few feet above the surface, so that flows can be expected only on ground of similar elevation or on the low bottom along the river. There are occasional private flowing wells in Three Rivers. It has been reported that a single well has been obtained in the St. Joseph Valley, in sec. 1, Lockport township, in which Three Rivers is located.

The following is a partial analysis of the public supply at Three Rivers. The water comes from a number of connected wells varying in depth from 75 to 108 feet. The analysis was furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well water at Three Rivers.

	Parts per million.		Parts per million.
Color	5	Carbon dioxide (CO_2)	101.13
Iron (Fe)	1.5	Sulphur Trioxide (SO_3)	10
Chlorine (Cl)	2.75	Hardness (as $CaCO_3$)	139

S. J. Lewis, analyst. Depth, 75 feet.

STURGIS.

The public supply at Sturgis is from a large open well 30 feet in diameter by 60 feet deep, in which four tubular wells 6 and 8 inches in diameter have been driven to a depth of 140 feet. The water stands 40 feet below the surface. The supply exceeds the present needs of the town, there being seldom a consumption of more than 125,000 gallons a day. The superintendent of waterworks has kindly furnished the following analyses, one being from the large open well, the other from the tubular well.

Analysis of Sturgis water supply.[a]

[Parts per million.]

	Open well.	Driven well.
Calcium carbonate	263.99	282.46
Magnesium carbonate	94.50	104.42
Calcium sulphate	45.34	45.02
Sodium chloride	45.02	45.02
Iron oxide and silica	3.42	3.94
Volatile matter	69.70	105.44
Total solids	521.97	586.30

[a] Expressed by analyst in grains per gallon; recomputed to parts per million at U. S. Geol. Survey.

CENTERVILLE.

Mr. S. J. Lewis reports that the Centerville plant is nearly obsolete and supplies water for little besides the main street. It seems to be largely for fire protection. It has three wells sunk so as to tap a large spring located at the head of Hawk Creek just below the town at 10 feet below the surface.

Below is given a partial analysis of the water, the data being furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Centerville.

	Parts per million.		Parts per million.
Color	15	Carbon dioxide (CO_2)	89.22
Iron (Fe)	Very slight trace.	Sulphur trioxide (SO_3)	10
Chlorine (Cl)	2.125		

S. J. Lewis, analyst. Depth, 10 feet.

CONSTANTINE.

This village uses Fawn River water as a public supply, but there are many private wells in use that range in depth from 15 to 60 feet.

WATER SUPPLIES OF CASS COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Cass County consists of a series of prominent moraines, between which are strips of gravelly plain, formed as an outwash from the bordering moraines. The moraines have wells of various depths up to 100 feet and more, there being apparently no uniform water table. The gravel plains have a water table usually 20 to 40 feet below the surface of the plains, but in places 60 feet below.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table contains data furnished by residents:

Village supplies in Cass County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cassopolis			Public supply from Stone Lake.							
Dowagiac		760	Waterworks from driven wells.	202			47	47	− 2	
Edwardsburg	400	±834	Dug and driven wells		25	27	25	25	−22	None.
Glenwood	72	750	Driven wells	138+	14	138	18	18	+ 8	Large.
Jones		921	Driven wells and lakes		14	60	50	40	(?)	
Marcellus		983	Waterworks and driven wells.	265			35	35		
Newburg			Driven wells		12	60	50	50		
Penn		904	do		18	75	25	20	−40	Small.
Vandalia	407	883	do		10	60	30	30	−25	Do.
Wakelee	200	913	do		25	65		50	−35	Do.

FLOWING WELLS.

Flowing wells have been obtained along Dowagiac Valley at Glen wood and north and west of Dowagiac, as well as in that town; als northwest of Marcellus at Fish Lake, and in a valley 2 miles east o Wakelee. None have been reported from other points in the county

GLENWOOD DISTRICT.

There are three wells near Glenwood on the Hampton stock farm two in the SW. ¼ sec. 3, and one in the NE. ¼ sec. 10, T. 5 S., R. 1 W One well has a depth of 138 feet, and the others are similar. The yield strong flows of hard water carrying iron. The catchment are seems likely to be in the moraine lying southeast of the wells. Spring are also abundant along the base of this moraine near Glenwoo Mrs. C. Wells has one in sec. 11, T. 5 S., R. 15 W., piped to suppl house and barn.

LONG LAKE.

About 5 miles west of Glenwood on the bank of Long Lake is the wing well of William Peterbaugh, but no data were obtained as depth or rate of flow.

South of this well in sec. 18, Wayne Township, A. F. Hatch has flowing well 36 feet deep that flows 2¾ gallons a minute; tempera-re 53° F. The well was made May 10, 1904.

WEST OF DOWAGIAC.

L. J. Pray, a driller at Dowagiac, states that J. C. Becker has a wing well west of Dowagiac near Dowagiac River, 77 feet deep, ith a head of 6 feet that will flow a barrel a minute from a 2-inch pe. The well was made in 1893. Water beds were struck at 20,), and 40 feet, as well as near the bottom.

Another well reported by Mr. Pray is on C. E. White's farm, west Dowagiac, and this has sufficient force to bring up fine gravel. flows about a barrel a minute. The well is 152 feet deep.

A flowing well west of Dowagiac on the farm of J. F. Cook in ec. 33, Silver Creek Township, was visited by M. L. Fuller and Jon . Udden in 1904. It flows 15 gallons a minute from a 2-inch pipe. he depth is 76 feet and diameter 2 inches. The water is hard and halybeate and has a temperature of 52° F.

Across the road from Mr. Cook's well, in the northwest part of Pokagon Township, is the well of J. C. Becker, noted above, which was shut off in August, 1904, while Fuller and Udden were there.

A well a mile south on the farm of E. W. Whitmore in sec. 9, Pokagon Township, had just been made in 1904, and flowed about 30 gallons a minute from a 2-inch pipe. The depth is 86 feet and altitude about 745 feet. The temperature is 52.5° F.

FISH LAKE.

A single flowing well is in operation on the shore of Fish Lake 3 miles west of Marcellus. It was put down for Doctor Davis and has a depth of 90 feet.[a]

WATERWORKS.

DOWAGIAC.

The waterworks at Dowagiac have eleven wells 100 feet deep, and two 47 feet deep, all but one being 6 inches, and that is 4 inches in diameter. There is also an open well 30 feet in diameter and 16 feet deep. The deep wells flow, and in the shallow ones water stands about 2 feet below the surface. The water has a temperature

[a] Data furnished by W. F. Cooper.

of 52° in the deep wells. The deeper wells appear to penetrate some clay near bottom, but the shallow ones pass through sand in which there are gravelly beds which yield water rapidly. The strongest supply is from the upper beds, which yield about 400 gallons a minute by pumping, while only 600 gallons a minute are obtained from the eleven deeper wells.[a]

The wells are not so strong as when first made, but the superintendent reports that water comes in as rapidly as the pumps can take it, for the water is pumped direct from the wells, and the vacuum gage shows that it does not decrease with pumping.

The superintendent furnished the following record of the shallower well:

Record of shallow waterworks well at Dowagiac.

	Thickness.	Total.
	Feet.	*Feet.*
Muck and fine sand	2	2
Coarse sand, pebbly	3	5
Fine sand	2	7
Gravel with cobblestones	15	22
Cemented sand and gravel	10	32
Fine gravel, water-bearing	15	47

CASSOPOLIS.

The public supply for this town is pumped from Stone Lake, but private wells are in common use, the depth being from 15 to 40 feet.

MARCELLUS.

The village of Marcellus obtains its public supply from driven wells 35 to 50 feet in depth. The pumping is direct with an ordinary pressure of 40 pounds and fire pressure of 90 pounds.

WATER SUPPLIES OF BERRIEN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Berrien is the southwest corner county of Michigan, with Lake Michigan on its western border and the State of Indiana on its southern. St. Joseph River traverses it nearly centrally from southeast to northwest, and, with its tributaries, drains all the county except the southwest corner and a narrow strip along the lake shore. In the southeastern part are plains of sand and gravel in which the water table is adjusted to the streams and lakes, and is tapped by wells at depths of 20 to 80 feet, the greatest depth being on an elevated plain west of St. Joseph River, just north of the State line

[a] Data by superintendent.

he city of Niles has sunk wells to a lower water horizon beneath a ıeet of clay for its public supply, and thus obtains flows. A promient morainic ridge east and south of Buchanan is surrounded by ravel plains and carries wells of depths ranging from 25 feet to ıore than 100 feet. The Valparaiso morainic system forms a belt to 10 miles wide that runs northward from Galien and Dayton, rosses St. Joseph River between Buchanan and Berrien Springs, nd then passes eastward out of the county south of Watervliet. Between two members of this morainic system, in Pipestone and Bainbridge townships, is a depression in which an important flowingvell district has been developed. Flowing wells have also been obtained along the inner or northwestern border of this morainic ystem near Galien and near Watervliet. In the moraines wells are of various depths and differ widely in head. Between the Valparaiso norainic system and the shore of Lake Michigan are till plains nterrupted by small till ridges. A narrow strip between the westernnost till ridge and the shore of Lake Michigan has been covered by ake waters, and in places is capped with dunes. A few flowing vells have been obtained in low places along the lake shore. This vestern part of the county, though much lower than the eastern, ınd probably in the line of underground drainage toward the lake, loes not display as strong hydrostatic pressure as might be expected. The wells are of various depths and seem to be supplied from water beds that are not widespread at any one horizon. A large amount of blue clayey till is found throughout the district between the Valparaiso morainic system and the Lake Michigan shore, but in this morainic system the blue till is interbedded with thick deposits of sand and gravel, while east of this morainic system the till is relatively scarce, except perhaps at considerable depth.

WATERWORKS.

Several towns in the county are supplied with waterworks, as indicated below. In those not thus supplied, the residents depend to a large extent on tubular wells driven to moderate depths, seldom over 40 feet. The dug wells made in the early days of settlement are being superseded by the less easily contaminated driven wells.

NILES.

Two systems of waterworks are in operation in Niles; one, taking its supply from Barron Lake, is owned by a private company; the other, taking its supply from driven wells, is owned by the city. The private works were built in 1879 and were the sole supply for about 16 years, when the city built its own works, because satisfactory terms could not be made with the private company.

The wells in the municipal plant are in St. Joseph Valley and are reported to have a head of several feet. The water is pumped from the wells to a standpipe and also direct to the mains. The reservoir pressure of 55 pounds may be doubled in case of fire. The average daily consumption is about half a million gallons. Water power is used in pumping. There are 15 miles of mains, 158 hydrants, and 763 taps. The cost of the plant is $175,000.

BUCHANAN.[a]

The public water supply of Buchanan is furnished by six wells 27 to 40 feet in depth and 6 inches in diameter, having a head nearly level with the surface. The water is pumped direct to the mains, with a day pressure of about 65 pounds and a night pressure of 30 pounds. In 1904, in prospecting for additional sources, the wells were carried to the rock. The water for the present supply is from gravel. The plant is municipal.

There were two flowing wells on low river bottom at Buchanan, but since the dam was built the land has been flooded and the wells abandoned.

THREE OAKS.[a]

The public supply of Three Oaks is owned by the municipality and is from one 6-inch well 76 feet deep and one 8-inch well 86 feet deep. The wells are largely through blue till but obtain water in a sandy gravel. The water in each well stands 30 feet below the surface. The combined yield is 125,000 gallons a day; this supply is scarcely sufficient in case of fire, but arrangements have been made with the Warren Featherbone Company to pump directly from a well at their factory into the village mains in case of fire.

BENTON HARBOR.[a]

Both springs and wells are in use and furnish an adequate supply for present need, but Lake Michigan will probably become the source of supply should the present prove inadequate or unsuitable.

The plant is municipal. The wells range in depth from 43 to 80 feet.

ST. JOSEPH.[a]

The public supply of St. Joseph is pumped from wells sunk in the bed of Lake Michigan a half mile or more south of the mouth of St. Joseph River. The wells are 25 feet deep and filled by gravity from the lake. The water is pumped to standpipe and to the mains direct, the ordinary pressure being 50 pounds and the fire pressure 100 pounds. The plant is municipal.

[a] Information furnished by Jon A. Udden.

EAU CLAIRE.

The village of Eau Claire is reported to have a partial public supply, which is obtained from wells and used for both fire protection and drinking.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table is largely made up from data furnished by officials to whom water-supply schedules have been mailed; it shows the conditions in 19 of the most important towns:

Village supplies in Berrien County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Baroda	300	640	Driven wells; cisterns.	.....	10	50	18	.....	−6	None.
Benton Harbor	.....	596	Driven wells; springs.	140	15	1,200	.....	.....	−12	Large.
Berrien Springs	808	650	Dug and driven wells.	110	15	670	25	25	−15 −25	Do.
Bridgeman	250	640	Mostly driven wells.	140 +228	12	800	100	150	−6	None.
Buchanan	1,708	680	Driven wells; springs.	60	40	60	40	40	−3	Strong.
Coloma	687	647	Driven wells	.....	48	99	50	48 60	−42	Medium.
Dayton	250	716	Driven and dug wells.	+90	20	90	25 50	25 50	.....	Large.
Eau Claire	.....	718	do	+120	16	120	16	120	−60	Small.
Galien	440	680	Driven wells	+100	17	100	30 40	30	−2	Do.
New Buffalo	629	587	Open and driven wells.	200	12	212	60	30	+2	Do.
New Troy	.....	625	do	65?	.....	120	.....	.....	.....	Do.
Niles	4,287	630 675	Driven wells; lake.	140 265	.....	1,438	110	110	(?)	
Riverside	150	637	Driven wells	.....	.....	.....	22	.....	.....	
St. Joseph	.....	590	Lake Michigan; driven wells.	133	.....	165	.....	.....	.....	
Sawyer	150	640	Open and driven wells.	125	12	150	+50	+50	.....	
Stevensville	250	630	Driven wells	.....	30	50	30 50	.....	−15	Medium.
Three Oaks	994	667	do	+140	40	140	80	80	−20	None.
Vineland	.....	587	Wells and stream	+100	20	100	20	.....	−15	
Watervliet	717	645	Driven wells	+95	40	95	50	40 50	−15	Large.

FLOWING WELLS.

GALIEN DISTRICT.[a]

Two flowing wells have been obtained on low ground, elevation about 660 feet, a short distance northeast of Galien village. One on the farm of William Goodrich, in the north part of sec. 2, was made in 1897; it is 44 feet deep, 1¼ inches in diameter, and flows 2.5 gallons a minute, with a head of 6 feet. The temperature is 53° F. The other well is in the northeastern boundary of Galien, in sec. 3, but no data concerning it were obtained.

[a] Information furnished by Jon A. Udden.

The catchment area for these wells in all probability is in the higher land in the Valparaiso morainic system to the south and east, and flowing wells can probably be obtained in other similar low tracts along the inner slope of the Valparaiso morainic system. One of these forms the next district discussed, but in most of these depressions no explorations have been made.

WEESAW TOWNSHIP.

There are three flowing wells along the valley or depression heading in the Valparaiso morainic system in southeastern Weesaw Township, about 3 miles north of Galien. The well of John Beckwith, in sec. 25, was made in 1895, is 92 feet in depth, and 2 inches in diameter; it flows 2¼ gallons a minute, with a head of 5 feet or more, and has a temperature of 53° F.

The well of F. Prinkert, in sec. 27, is 42 feet deep and 1¼ inches in diameter; it obtains water from gravel at 28 feet: It has a head of 12 feet, flows 8 gallons a minute, and has a temperature of 53° F.

A flow on sec. 23, on the property of Mrs. Gallivan, is noted, but no data are given.

NEW BUFFALO DISTRICT.[a]

There were several flowing wells near New Buffalo in 1887 when the writer mapped the glacial features of the region. These were on low ground, scarcely 10 feet above Lake Michigan, and had a depth of about 30 feet. From the lake there is a rapid rise to a till ridge in the eastern part of the village, which probably serves as the catchment area. The drift at the village extends to a level about 200 feet below Lake Michigan. Mr. Udden visited New Buffalo in 1904 and learned of three flowing wells in or near the village.

The well of Mr. Williams is 117 feet deep, 2 inches in diameter, and has a head of 1½ feet. The well mouth is noted by Udden at 619 feet. It flows one-half gallon a minute, with a temperature of 53° F.

Henry Gallwitzer has a well, which appears from Udden's notes to be at New Buffalo, that struck a flow at 46 to 50 feet in sand and gravel. The water is hard and is impregnated with iron.

Murdock & Co., of New Buffalo, are also reported by Udden to have a flowing well, but no data are given.

PIPESTONE DISTRICT.

The Pipestone district lies between two morainic ridges of the Valparaiso system in northeastern Berrien County in a basin drained by Pipestone Creek. The wells are mainly in Pipestone Township,

[a] Data by Frank Leverett and Jon A. Udden.

ılso are obtained in the southeastern part of Bainbridge Town- They occupy a belt about 5 miles in length and 1 to 2½ miles .dth, forming an area about 6 or 7 square miles (see fig. 13). first well was made in 1877, in the southwest part of sec. 2, ›tone Township, and several have been flowing since 1878. In , 51 wells were in operation. Within the limits of this district about a dozen wells were noted which do not flow, and these

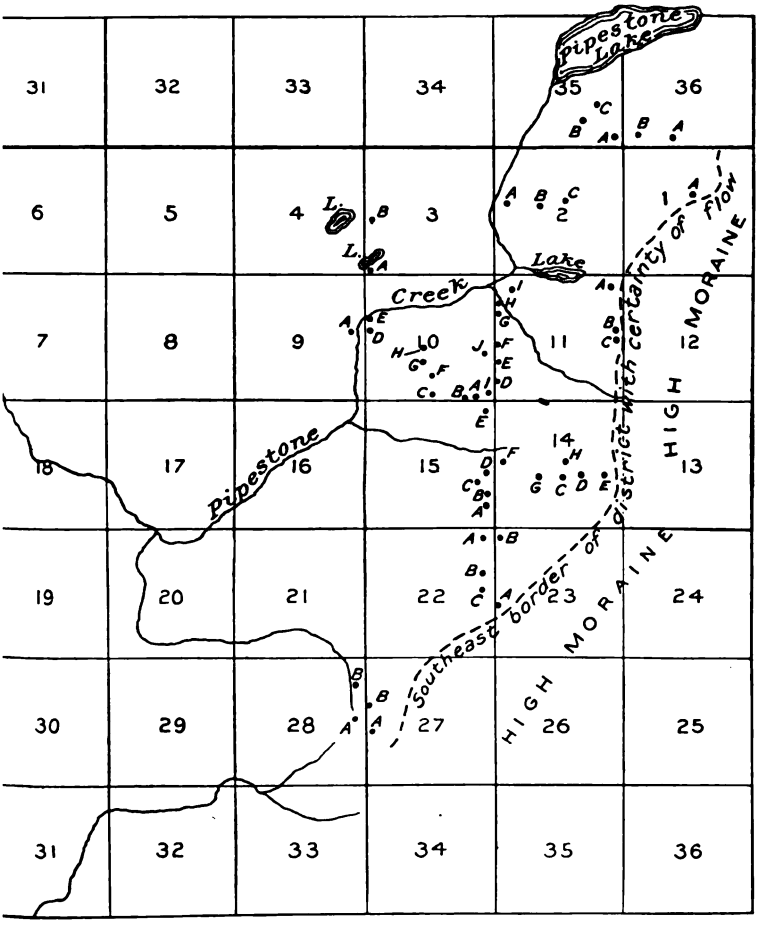


FIG. 13.—Map of Pipestone flowing-well district, Berrien County.

too shallow to reach the beds from which flows are obtained. combined discharge of the 51 wells was 116 gallons a minute, bout 170,000 gallons a day, but many of the wells have reducers re regulated by faucets, so that this discharge represents but a ll fraction of what the wells would flow if the pipes were left open. ›ably the district, as now developed, would yield more than),000 gallons a day, or enough to easily supply a city of 10,000

population. The water is used for cooling as well as for drink its uniform temperature of about 52° F. being well adapted creameries.

Wells which have received proper care appear to show little, if decrease in head, and seem to possess a uniform rate of flow throu out the year. Many of the wells have not been properly looked a and are clogging with sand or are in need of new screens. The w best cared for have been cleaned about once a year.

If properly distributed, many new wells could be put down in region without drawing seriously from those now in operation. well made in sec. 13 in 1904 flows 12 gallons a minute, and seems to interfere with the flow of neighboring wells.

The catchment area for this district appears to be in the mor lying east of it, which rises in places to an altitude of more than feet above the wells. Probably the gravel plain east of the mor also contributes to the supply, for it stands high enough to fur considerable head at the level of these wells.

The wells pass through a large amount of clayey till before reac the water-bearing sand and gravel, which forms an excellent c to prevent natural escape, and springs are consequently rather sc and weak. The water is highly mineralized in most wells, and fo a yellow coating where it discharges; the amount of mineraliza is such as to sustain the view that the water passes underground some distance—probably more than a mile—before it is tapped the wells. It is from medium to very hard.

The tabulated data given herewith were collected and arran by Jon A. Udden. The wells are all 2 inches in diameter, ex a 3-inch well of J. H. Price (E 10), and a well with 12-inch woo pipe (E 15) on the Rosenbaum farm:

Wells in Pipestone district.

Letter on fig. 13.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.[a]	Temperature.	Qua
				Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*	
A	1	Fred Wolf			725	725	R 0.5	53	
A	2	J. F. Hastens	1901	60	720	721	.75	53	
B	2	W. Bateman	1878	156	727	729	.75	52	
C	2	M. G. Matran[b]	1901	130	720	723	R 3	52.5	
A	3	E. Collins	1902	28	720	720.9	R .25	52	
B	3	P. L. Northrop			712	714	2	52.5	
A	9	J. H. Price			705	707	R 1.5	52	
A	10	E. O. Davis			710	712	.5	53	
B	10	W. B. Graham	1885	55	710	712	R 1.5	52	
C	10	Mr. Grieme[c]	1902	40	715	718+	R 1.5	52	
D	10	J. H. Price	1903	97	710	710	.75	52	
E	10	do	1899	57	675	679	R 2	52	
F	10	Clarke —[d]	1882	52	720	723	R 2	52.5	
G	10	Irvin Hague			718	719	R 2	52.5	

[a] Where wells are reduced the letter R is prefixed.
[b] Original head, 730 feet. Clay, 30 feet; quicksand, 30 feet, from which water came to the s blue clay, 65 feet, with hardpan crust at bottom covering the water gravel.
[c] Original head, 719 feet. Clay to within 2 feet of bottom.
[d] Original head, 732 feet. Water strong in iron.

Wells in Pipestone district—Continued.

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.
			Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*	
10	C. Bailey [a]	1901	40	720	722	R10	51.5	
10	M. J. Sheppard			712	714	R 2	52	Hard.
10	F. Hackstedt			714	716	.75	53	Do.
11	Fred Holler			720	722	2	52.5	Do.
11	Joe Dupree			720	721	1	53	
11	Charles Rush			720	723	R 3	52.5	
11	John Cannon	1894		720	721	1	53	
11	H. Vanecken [b]	1880	45	715	717	.75	53	
11	Bert Collins [c]	1900	62	715	717	R 2.5	53	
11	Frank Johnson			712	715	R 1	53	
11	B. Putterbaugh		40	712	714	1	53	
11	Charles Haskins		40	712	715	1	53	
14	O. Collins [d]	1899	117	712	713	2	52	
14	School District No. 3	1902		715	716	R 1.5	52	
14	E. W. Claussen	1890	60	713	715	R 1.5	52	
14	H. Frecky [e]	1885	60	710	712	10	52	
14	J. W. Kelley			700	703	3	51.5	
14	T. Langlin [f]	1896	100	712	715	.5	52	
15	Guy Hawkes [g]	1900	60	715	715	R 2	51	
15	C. F. Hartelrack	1902	60	710	712	R12	51.5	
15	Louis White [h]	1880	60	710	714	.5	53	
15	C. F. Hartelrack			710	714	R 1	52	
15	W. Rosenbaum [i]	1889	50	710	710+		52	
22	J. Aumeck [j]	1886	62	710	712	2	51.7	
22	N. Preston [k]	1900	75	710	712+	1.5	51.5	
22	Mrs. Walsh	1887	108	712	714	2.5	51	
23	Robert Gano [l]	1880	87	710	712	1	51.4	
23	John Aumeck [m]	1904	97	702	705	12	51.5	
27	Fred Och [n]	1878		710	712+	1.5	53.5	
27	Mrs. Kingsley [o]	1880	30	725	726	2	51.5	
28	Henry Price [p]	1902	36	710	713+	7	52	
28	Wm. Ferry		30	710	711	R .25	53	
35	John Smith		96	730	732	1	53	
35	L. C. Goodrich [q]	1894	96	730	732	1	53	
35	A. M. Stewart		96	733	735	.75	53	
36	F. Bateman [r]	1891	160	715	717	R 1	52.5	
36	T. Morlock [s]	1889	146	725	727	R 2.5	53	

ue clay, 35 feet; quicksand, 5 feet; water in gravel at bottom, strong in iron. Pipe has a 1-inch r.

ay, mainly blue, 40 feet; quicksand and gravel, 5 feet.

ter penetrating 50 feet of clay a weak flow was struck, but the well was continued through 10 feet of blue clay to a stronger vein in sand and gravel. The pipe has a 1-inch reducer. Cost said to

ue clay, 75 feet; sand, 30 feet; gravel, 12 feet. Cost, $30.

riginal head, 718 feet. Entirely through clay to gravel at bottom. Cost, $40.

ue clay, 60 feet; sand, 40 feet; gravel at bottom with water strong in iron. Cost, $45.

lue clay, 20 feet; sand and gravel, 20 feet.

low has decreased because of filling by sand.

-inch wooden pipe.

ntirely through clay to gravel bed at bottom. Well needs cleaning. Cost, $75.

ein at 27 feet had a head of 10 feet, and one at 75 feet had a head of 12 feet.

pes are rusted and flow is less on this account. Cost, $1.25 a foot. Sand and gravel, 12 feet; blue 74 feet; gravel with water at bottom.

riginal head, 716 feet; clay, mainly blue, 97 feet; fine sand, 20 feet. Cost, $46.

eeds cleaning. Formerly flowed 7 gallons a minute.

ogged with iron rust.

ay, 10 feet; quicksand, 18 feet; coarse gravel at bottom.

riginal head, 736 feet. Water strong in iron. Cost, 65 cents a foot.

riginal head, 723 feet. Blue clay, with streaks of sand, 135 feet; hardpan, 6 inches; gravel at bot-

riginal head, 743 feet, and original flow, a barrel a minute. Blue clay, 20 feet; fine sand, 80 feet; nd quicksand, 45 feet; blue clay, very hard, 1 foot; gravel at bottom. Cost, $90.

BAINBRIDGE DISTRICT.

here is a recess on the inner border of the Valparaiso morainic em, in the northern part of Bainbridge Township and southeast- part of Watervliet Township. It occupies about a square mile, ly in the west half of sec. 2 and east half of sec. 3, Bainbridge nship, there being but one well north of the township line (see

fig. 14). In this district the principal group is on the farm of Henry Gerling in the southwest part of sec. 2. One well furnishes water power to run a feed mill and 5 others are used to supply the house and stock. Mr. Udden visited this group of wells, but in the absence of the owner was unable to get data as to the yield and the power furnished. The wells vary in depth and obtain water apparently from two or three different beds of gravel or sand in the till.

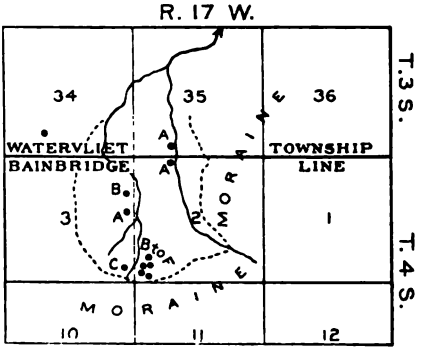


FIG. 14.—Flowing wells in Bainbridge and Watervliet townships, Berrien County.

This district may be capable of extension to the north, but the morainic hills which border it on the east, south, and west prevent extension in those directions. The catchment area in all probability lies on these bordering hills.

W. F. Cooper obtained data concerning a well reported by the owner, Charles Wasco, to be in sec. 6, Bainbridge Township. This was not visited by Mr. Udden. If correctly located it lies in a different district from that under discussion.

The data collected by Mr. Udden and also data from Mr. Cooper are embraced in the following table:

Wells at Bainbridge.

Letter on fig. 14.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	°*F.*
A	2	Nicolas Moser		2	100	700	702+	3	51
B-G	2	Henry Gerling[a]	1892	2	30	690	700+	.....	51
			1902	4	80	.....	.....	.....	.....
A	3	J. Warsko[b]	1903	2	45	705	707	3	51
B	3	Township well	1904	2	40	703	705	.75	52
A	6?	Charles Warsko[c]	1892	2	45	.....	+10	25	.....
A	35	H. W. Harr[d]	1903	2	89	.....	+10	3	50?

[a] Henry Gerling has five 2-inch wells and one 4-inch well ranging in depth from 30 to 80 feet. The large well furnishes water power to run a feed mill for home use. The wells obtain their supply from sand and gravel beds, the principal bed being at about 50 feet. The average cost per well is $50.

[b] Blue clay hard toward bottom, 43 feet, gravel 2 feet. Cost, 85 cents a foot.

[c] Data are from a schedule filled out by Mr. Warsko, in which he placed the well in sec. 6, but possibly it is in sec. 3.

[d] Data furnished by driller, J. Fritz, of Coloma. Water veins occurred at 36 and 55 feet. The casing is 17 feet. The well supplies house, barn, and fish pond. It is located just north of the line of Watervliet and Bainbridge townships in Watervliet Township. Cost $64.40.

PAWPAW LAKE.

On the north side of Pawpaw Lake in Watervliet Township, northern Berrien County, is a flowing well on the property of J. K. Blachford. It is 75 feet deep and 2 inches in diameter, but has only a half-inch escape pipe. The altitude is about 625 feet and head 3 feet or more.

WATER SUPPLIES OF VAN BUREN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Van Buren County lies north of Berrien and Cass counties, with a narrow frontage on Lake Michigan. Its principal stream is Paw-paw River which runs westward through the central part of the county. South Black River drains the northwestern part, and Dowagiac River the southeastern. A part of the lake shore is bordered by high sand dunes.

Morainic systems traverse the county in a northeast to southwest direction, the Kalamazoo system crossing the southeast corner, the Valparaiso system the central part, and the Lake Border system the western part. The Kalamazoo system is largely of loose-textured drift which absorbs rainfall rapidly and presents a rather deep-lying ground-water table. The loose-textured drift is unfavorable for flowing wells on its inner border though the altitude there is much lower than on the morainic ridges. There are sandy plains between the Kalamazoo and Valparaiso morainic systems in which flowing wells seem to be obtainable only on the low ground along streams or around lakes.

In the Valparaiso morainic system there is great variation in texture of drift as well as great irregularity of surface. In low parts of the moraines till is usually present, and water rises nearly to the surface in the wells and in a few places overflows. The high parts of the moraines are usually of loose-textured drift, and the head is not sufficient to bring the water near the surface. West of the Valparaiso system are plains partly of till and partly of sand, in which water rises about to the surface and occasionally flows from wells that go to considerable depth. The head is especially high in recesses on the immediate inner border of the Valparaiso morainic system, and flows are obtainable in some of these recesses. Flows are also obtainable in this plain near South Black River in the northwest part of the county.

A ridge of clayey till, known as Covert Ridge from Covert village standing on it, runs across the western end of the county at a distance of 2 to 4 miles back from Lake Michigan. On this ridge and on its inner slope wells often reach considerable depths, and the water does not flow even on the slopes or on the plain between this village and the lake.

Hon. C. D. Lawton, of Lawton, who is one of the early settlers in this region, states that springs seem to him to be weaker in the southwestern part of Michigan than when the country was first settled. They are still of such strength, however, as to supply a strong dry-weather flow to most of the streams.

WATERWORKS.

BANGOR.[a]

The Bangor waterworks are municipal. The supply is from wells about 60 feet deep, in which water stands 7 to 9 feet below the surface. An excavated well 14 feet deep receives the water, which is pumped to a tank with a capacity of 50,000 gallons. The pressure is 55 pounds to the square inch. The plant was put in operation in 1903.

DECATUR.[b]

The supply is from two 6-inch wells 90 and 115 feet deep, with water 32 feet below the surface. The wells yield 400 gallons a minute, and are seldom lowered more than 10 feet by pumping. One well is cased 81, and the other 90 feet. There was some water at 36 to 60 feet but this was cased out. The waterworks, which are municipal, were installed in 1895. The pumps are placed in a pit 28 feet deep and deliver the water to a standpipe 115 feet high.

HARTFORD.[c]

The Hartford supply is from wells 40 to 42 feet deep, with water about 10 feet below the surface. Water is pumped to a tank. The plant is municipal.

LAWRENCE.[c]

The supply is from two 6-inch wells, 60 feet deep, which yield about 40 gallons a minute. The water is pumped direct to the mains. The plant is municipal.

PAWPAW.[a]

At Pawpaw there is a large well 20 by 25 feet, in the bottom of which two 6-inch wells are drilled about 40 feet; the water rises into the excavated well about 17 feet. Four hours are required in dry weather and about three hours in wet weather to fill it to that level the first 9 feet will fill in one hour. The water is pumped to a standpipe 120 feet high, which gives a pressure of nearly 60 pounds. In case of fire direct pressure is applied. The works are municipal They were installed in 1893 at a cost of $20,000. There are 6.5 miles of mains, 40 hydrants, and 318 taps.

SOUTH HAVEN.[d]

The supply is from horizontal Cook wells pumping to a standpipe The wells are pushed into sand 8 feet below the bed of Lake Michigan

---

[a] Information furnished by Jon A. Udden.
[b] Information furnished by I. B. Galbraith, superintendent of waterworks.
[c] Information furnished by postmaster.
[d] Data mainly from Manual of American Waterworks.

and consist of several 8-inch pipes 150 feet long. The standpipe has a capacity of 140,000 gallons. The plant was built in 1892 at a cost of $37,000; it is owned by the village.

The following partial analysis of the water from the Rector well at Hartford was furnished by M. O. Leighton, of the United States Geological Survey:

Partial analysis of well water from Hartford.

	Parts per million.		Parts per million.
Color	5	Carbon dioxide (CO_2)	122.46
Iron (Fe)	Good trace.	Sulphur trioxide (SO_3)	20
Chlorine (Cl)	2.75	Hardness (as $CaCO_3$)	+139

S. J. Lewis, analyst.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table presents data on village supplies which have been obtained largely by correspondence with residents:

Village supplies in Van Buren County.

Town.	Population.	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed	Head.	Springs.
		Feet.		Feet.	Feet.	Feet.	Feet.	Feet.	
Bangor	1,021	650	Driven wells and waterworks wells.	18	70	30 60	60	−10	Small.
Bloomingdale	379	730 750	Flowing wells, other driven wells.	20	220	38	38	+9 −15	Do.
Breedsville	236	667	Driven wells, river, springs	78	100	40	40	−15	Do.
Covert			Driven wells	10	110	80	80	−25	None.
Decatur	1,356	780	Driven wells at waterworks	40	125	90	90 115	−32	
Gobleville	506	800	Driven wells	35	100	50	50	−40	Small.
Grand Junction.		680	do	12	72	30	30	−10	Do.
Hartford	1,077	662	Driven wells, including waterworks.	12	42	25	25	−12	
Keeler		800	Driven wells	20	125	35	35		Do.
Kendall		780	do	12	50	25	25	−20	Do.
Kibbie		630	do	11	25	15	15	−10	None.
Lacota		700	do	25	80			−15	
Lawrence	598	700	Driven wells, including waterworks.	25	100	60	55	−20	Small.
Lawton	942	776	Driven wells	10	60	25	25	−15	Do.
Mattawan		858	do	28	115	35	35		
Pawpaw	1,465	730	Driven and open wells, including waterworks.	20	60	30		+2 −6	
South Haven	4,009	588 630	Waterworks from Lake Michigan and private driven wells.	20	347	100	100	−20	

FLOWING WELLS.

HARTFORD TOWNSHIP.

Flowing wells have been obtained in 4 small pools in Hartford Township (T. 3 S., R. 16 W.)—one near Rush Lake, in the northwest part; another in the valley of Pawpaw River, in the west part; a third along a small tributary of Pawpaw River, in the southwest corner of the

township; and a fourth in the headwaters of Pine Creek, in the southeast part. No data were collected concerning the first and second districts. In the third the data on a single well, that of O. S. McGowan, was obtained by W. F. Cooper through correspondence with the owner. The well is in sec. 31, and was made in 1885. The depth is 44 feet, water being struck at 40 feet in gravel under clay. The head is 10 feet above the surface, and the flow is about a half-inch stream. The water has been piped to the kitchen and also supplies stock. It is medium hard, with some iron. The cost of the well and piping was $75.

The fourth district, in secs. 26 and 27, includes 4 wells on the farm of Easton Brothers, of Hartford, and 4 others on farms of Fred Warren, W. P. Smith, John Ray, and Charles Floate, all of which were reported to W. F. Cooper by Easton Brothers. The Easton wells are about 58 feet deep, and obtain water in gravel near the bottom. There are 30 feet of sandy drift at the surface, below which is blue clay to the water-bearing gravel. One or more of the wells have been in operation since 1887, and together they now yield about 300 barrels a day. The flow appears to be regular throughout the year. The Smith well, made in 1886, is about 68 feet, and the Warren well, made in 1892, 58 feet deep. Mr. Udden visited these wells in 1904, and found the Smith well to flow 3 gallons and the Warren well 2½ gallons a minute, while one of the Easton wells flowed 7 gallons.

This district and that in sec. 31 are each in a recess in the Valparaiso moraine, which forms the catchment area and governs the head.

PAWPAW TOWNSHIP (T. 3 S., R. 14 W.).[a]

In addition to the flowing wells at the Pawpaw waterworks, which, as noted above, discharge into a large open well, there are occasional flows on low ground in that vicinity. The head is probably from a catchment area on higher ground to the southeast. One well, on the farm of Aaron Hathaway, in the southwestern part of sec. 23, 2 miles south of Pawpaw, in the valley of West Pawpaw River, is flowing about 2 gallons a minute, with a head of 1½ feet. The well is 45 feet deep, 1¼ inches in diameter, and cost $30. It was made in 1901.

The two partial analyses given below show the qualities of waters obtained from the shallow wells at Pawpaw. The situation of this type of shallow wells within the city is such that they are liable to contamination and are unsafe sources of domestic supplies. The data were furnished by M. O. Leighton, of the United States Geological Survey.

[a] Data collected by Jon A. Udden.

Partial analyses of well water from Pawpaw.

[Parts per million.]

	1.	2.
.....	24	5
.....	Very slight trace.	None.
).....	1.5	2.75
ide (CO_2).....	76.73	80.03
xide (SO_3).....	0	0
s $CaCO_3$).....	139+	15

s, analyst. 1. City well; depth, 20 feet. 2. Dykeman House; depth, 30 feet.

ANTWERP TOWNSHIP.[a]

red Bassett has a flowing well 2 miles northeast of Lawton, alley of a tributary of Pawpaw River, in the northwest corner 2, Antwerp Township (T. 3 S., R. 13 W.). It was made in 1904, is only 13 feet deep, and has a head of 8 feet. It dis- 12 gallons a minute from a pipe 1¼ inches in diameter. The ture is 52° F. The water supplies a trout hatchery known Glen Spring Trout Company." This valley could probably loped for other flows, either from this shallow source or from sources. The prominent Kalamazoo moraine to the east good catchment area.

WAVERLY TOWNSHIP (T. 2 S., R. 14 W.).[b]

t 8 miles northwest of Pawpaw, in the valley of Pawpaw a group of 8 flowing wells, 7 being in sec. 30 and 1 in sec. 31, Township. (See fig. 15.) One well is 63 feet and the others een 45 and 50 feet deep. They are mainly through blue clay -bearing gravel at bottom. Most of them were made between d 1884, and, with one ex- are reported to flow with strength as when first ndeed, the owners think the wells are increasing f flow. They have always y weak, however, flowing or less per minute, except ell, that of W. North, which out 9 gallons. It is this well that is thought to creased in rate of flow; it 15 feet deeper than the others, and probably struck into a d better water bed. It rises to about 6 feet above the sur- ile the others will rise to but little more than 1 foot. The hard and strong in iron. The wells are all north of the river,

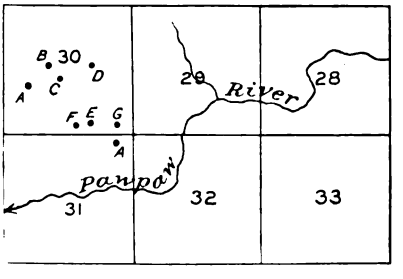


FIG. 15.—Map of Waverly flowing-well district, Van Buren County.

tion furnished by Jon A. Udden.
inly collected by Leverett in 1887, but the district was visited by Udden in 1904 The s by Udden.

the ground on the south side being too high for a flow. The co to the east probably serves as the catchment area.

Wells at Waverly.

Letter on fig. 15.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Casing.	Flow per minute.	F f
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	
A	30	W. North	1884	1.25	63	+5.5	50.4	9	Gr
B	30	O. Y. Culver	1880	2	49	+1	9	.75	Le
C	30	C. B. Smith	1884	2	49	+ .5		.5	
D	30	L. Crawell	1903	2	50	+1		.5	
E	30	Albert Cornell	1889	1.25	50	+1		.5	
F	30	do			49	+1		1	
G	30	W. Beeching	1884	1.25	49	+1	14	.5	
A	31	John Brooks	1880	1.25	45	+1	15	.75	

On the Snow farm, in sec. 2, there is a single well at the we base of a morainic ridge that runs north toward Gobleville. Th is 58 feet deep, and is in clay, except 8 feet of gravel at the bo The head is scarcely 1 foot. Probably other flowing wells cou obtained on the lowest ground along the inner border of this mo

ARLINGTON TOWNSHIP.

There is a group of flowing wells in a marsh in the northeast of Arlington township (T. 2 S., R. 15 W.), in secs. 11, 12, 13, ar (See fig. 16.) Four of the wells were put down by H. Hogm obtain water for use in a pe mint factory to strain and di the peppermint and to coo coils in the distillery. The c are used to supply stock in tures. With the exception c two shallow Hogmire wells, 2 28 feet, the wells are about 5 in depth, and pass through 4 or more of blue clay. Ther thin deposit of muck and above the clay, usually 5 to 1 thick. The water is from sa gravel, and is hard and stro iron. The catchment area is ably in the higher land on th mediate border of the bas which the wells are situated. further development of fl wells will be restricted to th marshy ground on its immediate borders. This marsh extends s eastward into Waverly Township, about 2 miles farther than have yet been developed, and farther extension of the distri that direction may be expected.

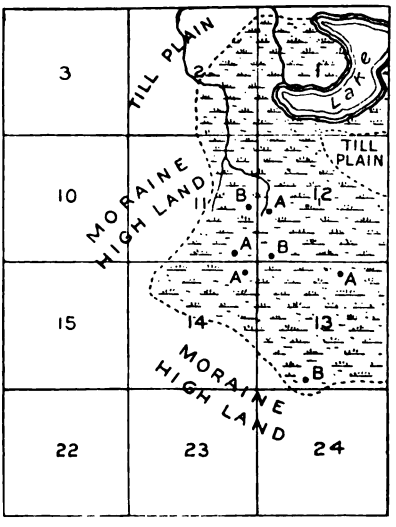


FIG. 16.—Arlington Township flowing wells, Van Buren County.

Wells in Arlington district.[a]

Letter on fig. 16.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Cost.	Flow per minute.
				Inches.	*Feet.*	*Feet.*		*Gallons.*
A	11	Mr. Slupeck	1902	2	50	+1	$70	0.5
B	11	M. H. Hogmire		1.25	27	+6		
A	12	do		1.25	28			
B	12	do		1.5	51			.5
A	13	do		1.25	47			5
B	13	Charles Mohns	1904	2	68	+3	50	3
A	14	A. Couleson	1898	1.25	50	+3	15	.5

BANGOR TOWNSHIP.

The greater part of Bangor Township (T. 2 S., R. 16 W.) is unfavorable for obtaining flows, but there are occasional low tracts, either basins or long sags traversed by drainage lines, in which it is possible to obtain flowing wells. Mr. Udden noted the following wells:

Davis Clinard, in sec. 8, has a well from gravel; depth, 47 feet; diameter, 2 inches; water within 1 foot of surface. Bruce Kinney, in sec. 15, has a flowing well; no data concerning it.

G. W. Overton, in sec. 18, has a well 42 feet deep that flows with a head of 1½ feet. The well penetrated muck 10 feet, blue clay 30 feet, and gravel 2 feet.

GENEVA TOWNSHIP.

A flowing well was obtained some 20 years or more ago on the farm of Irving Pierce in the southwestern part of Geneva Township (T. 1 S., R. 16 W.) at a depth of 230 feet. It penetrated 190 feet of drift, largely blue till, and 40 feet of shale rock. The water rises 7 feet above the surface and the flow is weak.[b]

Mr. M. W. Hyenga has a well, in sec. 24, that flows 2 gallons a minute. Its depth is 48 feet, diameter 2 inches, head 16 feet, temperature 52° F. The well is said to flow stronger than usual if a stiff southwest wind is blowing. The water is from fine sand.

The head in the waterworks well, in Bangor, is such that a flow could be obtained at the level of the lowest ground along Black River.

COLUMBIA TOWNSHIP.

Mr. Udden ascertained that thirty years ago there was a flowing well at Breedsville on P. A. England's property near Black River, about 15 feet below the level of Breedsville station, or 652 feet above tide. The head was 7 feet above the surface. The well was very popular for drinking. The notes seem to indicate that it has ceased flowing.

[a] Data collected in 1904 and arranged by Jon A. Udden.
[b] Information obtained by Leverett in 1887.

F. L. Pease has a weak flowing well in Breedsville that barely drips. It is about 25 feet deep.

About 2 miles east of Breedsville, in sec. 34, Columbia Township, is a flowing well on the farm of John Quackenbush, that has been running for twenty years with no apparent decrease, and now discharges 3 gallons a minute. It is 54 feet deep, 2 inches in diameter, and has a head of at least 2½ feet. It penetrated sand 3 feet, blue clay 50 feet, and gravel at bottom.

It is probable that flowing wells may be obtained along the lowland bordering Black River from Breedsville eastward past the Quackenbush well, and also down the valley to Bangor. The highland south and east furnishes a natural catchment area capable of giving strong head to wells along the valley.

BLOOMINGDALE.

In the south part of the village of Bloomingdale are several flowing wells about 40 feet in depth. They are all south of the Michigan Central Railroad, the altitude north of the railroad being too great to permit a flow. The water rises 3 to 9 feet above the surface, according to height of well mouth, the full elevation being but little above the level of the Michigan Central tracks near the depot, 732 feet. The land east from Bloomingdale rises to about 810 feet on the moraine between Bloomingdale and Gobleville.

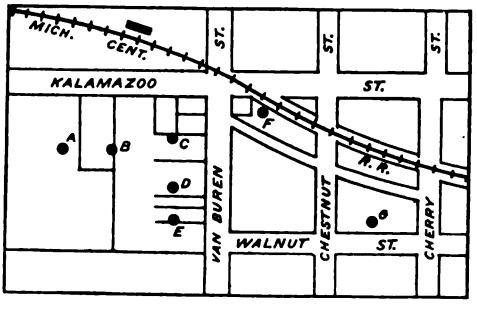


FIG. 17.—Map of part of Bloomingdale, Van Buren County, showing distribution of flowing wells.

The plat of Bloomingdale village (fig. 17) shows the distribution of the wells. This plat and the few data concerning the wells just given were obtained by Jon A. Udden.

PINE GROVE TOWNSHIP.

Mr. A. M. Todd of Kalamazoo has flowing wells on his mint farm in sec. 25, Pine Grove Township (T. 1 S., R. 13 W.), which is in a swamp bordering Pine Creek. No data concerning the wells were obtained. They were reported by D. W. Broadhead of Kendall, Mich.

This swamp is several miles long north and south, and lies at the base of a very prominent drift ridge. The situation seems favorable for flowing wells the entire length of the swamp.

WATER SUPPLIES OF KALAMAZOO COUNTY.

By FRANK LEVERETT.

TOPOGRAPHY.

A gravel plain about 15 miles wide runs across Kalamazoo County from north to south through the central portion and another covers most of the northwestern township. The Kalamazoo morainic system, which traverses the northwestern part, lies between these plains and includes another plain between its two ridges, which are largely of gravel and sand. It occupies northwestern Cooper, southeastern Alamo, most of Oshtemo, and the western part of Texas Township. In the eastern part of the county, in Charleston, Climax, Wakeshma, and Brady townships, there is a till tract covering about 100 square miles, including, however, around the village of Climax, a gravel plain of several square miles. Kalamazoo River traverses the northeastern part and drains much of the northern half of the country. The southern half is mainly tributary to St. Joseph River. Lakes abound in the moraines and gravel plains, but are not numerous on the till tract in the southeastern part.

On the Kalamazoo morainic ridges and on the elevated gravel plain in the central and northern part of the county, water is seldom obtained at a depth of less than 50 feet, and frequently only at more than 100 feet. The water table in these tracts is probably about on a level with the surface of lakes and streams, which are usually in deep basins or channels. But toward the south end of the county the lakes are about on a level with the gravel plain and wells are obtained at shallow depths. In the gravel plain in the northwestern part of the county also wells are shallow, for it is a comparatively low plain, with the water table near the surface. The till tract in the eastern part of the county usually affords wells at moderate depths of 25 to 40 feet, but in places they are driven 100 to 200 feet if water-bearing beds are wanting or inadequate for a strong well. Flowing wells are obtained only in the valley of Kalamazoo River in or near Kalamazoo.

WATERWORKS.

KALAMAZOO.

The city of Kalamazoo obtains its public supply from wells in the drift at its pumping station in the southern part of the city. The wells are in the edge of a shallow valley excavated in the broad valley of Kalamazoo River and are near the south bluff of the river.

The first waterworks plant was built in 1869 and reconstructed in 1884. The total cost to date for construction and repairs has been

about $750,000 There are at the pumping station two Gaskell pumps with a capacity of 3,000,000 gallons each. The distribution system April 1, 1905, comprised a total of 297,042 feet, or about 56½ miles, as follows:

Kalamazoo distribution system.

	Feet.
24-inch suction pipe or siphon	2,[illegible]
20-inch mains	1,[illegible]
16-inch mains	4,741
12-inch mains	2,276
10-inch mains	35,087
8-inch mains	50,770
6-inch mains	102,308
4-inch mains	94,622
2-inch mains	200
	297,042

The ordinary pressure is 45 pounds to the square inch and the fire pressure 80 to 90 pounds at the pumping station. The city stands mainly in the river valley at a level differing but little from that of the pumping station.

The water supply is in part from a large open well 22 feet in diameter and 32 feet deep, and a second large well around which are 13 tubular wells 6 inches in diameter and 80 to 120 feet deep, which overflow into it. The wells from top to bottom are in sand and gravel saturated with water. The depth of the tubular wells varies with the distance to a gravel bed that screens readily, much of the material passed through being rather fine sand. The water would rise in the tubular wells to 2 or 3 feet above the surface, but is turned into the large well, at 8 to 10 feet below the ground in order to increase the yield. The rate of flow from these wells is as high as 250,000 gallons a day from a single well when working most favorably, but some wells have diminished because of rusting of the pipes and consequent leakage. In one case a well which at first yielded only 50,000 gallons a day was so developed by proper adjustment of the screen as to yield a much larger amount. The maximum yield from the 13 tubular wells has been about 2,000,000 gallons a day, but the yield at any particular time will depend upon the condition of each well at that time. The open well can be depended on to furnish about 3,000,000 gallons a day, and constitutes the chief supply for the city.[a]

The insane asylum at Kalamazoo has a waterworks supply independent of the city system. It is derived from nonflowing drift wells. The number of inmates is about 1,660 and of employees 300 making a total of nearly 2,000 consumers.[b]

[a] Data obtained from the engineer of waterworks.
[b] Data obtained from Dr. E. A. Christian, March, 1906.

Analyses of Kalamazoo waters.[a]

[Reduced to parts per million.]

	1.	2.	3.
$CaCO_3$	180	140	150
$CaSO_4$	21	23	22
$Fe_2O_3+SiO_2$	.....	4	.....
$MgCO_3$	62	67	101
SiO_2	9	.....	.....
NaCl	.....	23	7
Volatile matter	36	43	30
Total matter	371	300	320
Total hardness	16°	14°	.....
Permanent hardness	5°	6°	.....
Nitrates	1	.5	.....
Free ammonia	.02	.05	
Albuminoid ammonia	.02	.02	.....
Oxygen from permanganate	.28	.25	.....

In the following table are given a number of additional partial analyses from the vicinity of Kalamazoo, showing the relative composition of the public water supply in the river water and the water from flowing well at the Bryant paper mill. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters near Kalamazoo.

[Parts per million.]

	1.	2.	3.
Color	10	46	5
Iron (Fe)	2	1	0
Chlorine (Cl)	4	1.5	2.5
Carbon dioxide (CO_2)	95.85	87.68	88.73
Sulphur Trioxide (SO_3)	0	−29	−29
Hardness (as $CaCO_3$)	.....	.....	+139

S. J. Lewis, analyst. 1. Bryant paper mill; depth 125 feet. 2. River. 3. Public supply; depth 30 feet.

VICKSBURG.

The public supply at Vicksburg is from three 6-inch wells 60 feet deep, from which water is pumped direct to the mains. An ordinary pressure of 50 pounds, and a fire pressure of 90 pounds is given. The works were established in 1897 at a cost of $12,000.

FULTON AND OSHTEMO.

Fulton and Oshtemo have partial systems of waterworks, water being pumped to a tank for village use. The village of Fulton built the tank and sunk the well, but the tank and well at Oshtemo were put in by M. Gibbs. The terms on which water is furnished have not been ascertained.

[a] Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, pp. 39–40.

MISCELLANEOUS VILLAGE SUPPLIES.

Reports showing general conditions in several towns in this county have been obtained by correspondence with residents, and the results are tabulated below:

Village supplies in Kalamazoo County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alamo		765	Driven wells	25	50	25	25	.....	Small.
Augusta	541	800	Driven wells; Kalamazoo River.	25	150	30	30	.....	
Climax	398	975	Open and driven wells	30	40	30	30	−20	None.
Fulton	275	900	do	10	50	25	25	−10	Do.
Galesburg	689	785	Driven wells	18	50	30	30	−20	Small.
Oshtemo	125	960	do	90	100	100	95	−75	Do.
Portage	.....	860	Driven wells; creek	12	35	28	28	−15	Do.
Richland	312	928	Driven wells	45	130	50	50	−45	None.
Schoolcraft	859	883	do	15	50	40	40	−20	Do.
Vicksburg	972	857	Lakes and driven wells, including waterworks wells.	20	60	50	50	−10	Do.
Yorkville	.....	972	Driven wells	40	80	80	70	−40	Do.

FLOWING WELLS.

There are two flowing wells in Kalamazoo at the Bryant paper mill in Portage Creek Valley a short distance east of the waterworks wells and on ground perhaps a few feet lower. One well, 6 inches in diameter and 143 feet in depth, which was made in 1901, has a head of 24 feet, and is estimated to flow 300,000 gallons a day. The strong flow was struck at 122 feet, and the water bed is 22 feet thick; the well passed through 50 feet of blue clay under the surface gravel before striking the vein.

The data concerning this well were furnished by the driller, James A. Newell, of Kalamazoo, who states that this is only one of several artesian wells in the vicinity. He has never struck a flow in a well closer to the river than these, which are about a mile from it. Notes collected by Jon A. Udden state that Henry D. Knowles drilled a well 122 feet for this paper company that will flow 250 gallons a minute from a 6-inch pipe.

In notes collected by Mr. Udden reference is made to three other flowing wells which appear to be in Kalamazoo. One on Vine street is 47 feet deep, 1¼ inches in diameter, and flows 3 gallons a minute. Another, not located, is 78 feet deep, and 2 inches in diameter, and flows 5 gallons a minute; it passed through coarse gravel 25 feet, black soil 15 feet, blue clay 35 feet, and gravel 3 feet; it was drilled by Mr. Knowles and cost $68. A gas company, apparently in Kalamazoo, has a well 60 feet deep and 6 inches in diameter, in which water rises to the surface. It penetrated gravel and clay 48 feet, blue clay 4 feet, and gravel 6 feet; the cost was $120.

WATER SUPPLIES OF CALHOUN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Calhoun County, which lies east of Kalamazoo County, has extensive gravel plains following its principal streams, and loose-textured drift in moraines and uplands outside the gravel plains. The Marshall sandstone, which forms the bed rock under the drift in much of the county is also loose-textured and a great water-bearer. This sandstone rises in hills in the eastern part of the county, but in the central and western parts the drift knolls and ridges give the relief above the gravel plains. A prominent moraine of the Saginaw lobe runs across the northern part of the county, and a somewhat complex system of moraines across the southern half, all trending from east to west. Kalamazoo River runs westward across the county a little north of the middle, and together with Battle Creek, a northern tributary, drains the northern half of the county. The southern part of the county is drained by the St. Joseph and its tributaries.

This county has generally abundance of water for wells at moderate depth, wells being usually but 20 to 40 feet, though on the high gravel plain north of Kalamazoo River they are 75 feet deep. Outside the cities water is generally obtained in the drift, but in the cities many wells have been sunk into the Marshall sandstone. This sandstone furnishes the public supply for Albion and Marshall, and tests are now being made to determine if the city of Battle Creek may not also take its supply from this source.

WATERWORKS.

ALBION.

The city of Albion draws its supply from a group of flowing wells on low ground near Kalamazoo River. Those first made are 110 to 114 feet, but one made in 1902 is 176 feet. They have a head 8 to 10 feet above the surface or about 940 feet above tide. In the well made in 1902 the principal supply is from a depth of 164 to 176 feet, and it will furnish by pumping 400 gallons a minute. Its head is 9 feet, and it, as well as the others, discharges into the waterworks reservoir, whence the water is pumped to a standpipe 128 feet high with a capacity of 108,000 gallons.

BATTLE CREEK.

The present supply is from Goguac Lake, which stands near the southwest edge of the city at an altitude about 80 feet above the business part. Water is pumped to a standpipe. Wells are being

sunk (in 1904) in Battle Creek valley and at other points near the city to obtain a supply less objectionable than the present, since inhabitation of the shore of the lake threatens to pollute the water.

MARSHALL.

The city of Marshall is supplied from wells in the sandstone, as at Albion, and water is pumped to a standpipe 100 feet high, with a capacity of 235,000 gallons.

MISCELLANEOUS VILLAGE SUPPLIES.

The following tabulated data on village and city supplies were obtained from personal visitation and correspondence with residents:

Village and city supplies in Calhoun County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Albion	4,519	940	Wells in sandstone and drift; Kalamazoo River.	10	20	176	110	164	+8	Large.
Athens		885	Driven wells		20	40	30		−20	
Battle Creek	18,563	820	Goguac Lake and rock wells; Kalamazoo River; Battle Creek.	10	20	100	80	80	+ 5	Small.
Burlington	334	+930	Open and drilled wells; stream.	30	10	108	12-20	16-20	−15	Do.
Clarendon		973	Driven wells	75	10	100	20	20	−25	None.
Homer	1,097	990	do	90	24	190	30		−17	
Joppa	20	916	do	+65	8	65	18			
Marengo		920	Driven wells; Kalamazoo River.	60	20	60	30	50	−20	
Marshall	4,370	820	Wells in sandstone; Kalamazoo River.	20	20	100	80	80	−20	
Partello	100	+950	Open and driven wells; springs.	+50	16	50	45	45	−30	Medium.
Tekonsha	573	945	Open and driven wells.		15	30	20	20	−15	Small.

FLOWING WELLS.

So far as ascertained no flowing wells from the drift have been obtained in Calhoun County, except around Battle Creek, in tests for a city supply, and there the water is obtained at the top of the rock. Flowing wells may be obtained from the Marshall sandstone on low ground along Kalamazoo River and Battle Creek, from Battle Creek up to Albion, at depths of 75 to 200 feet or more. Tests of the capacity of wells at Verona, a suburb of Battle Creek, in Battle Creek Valley, showed that strong pumping of one well would affect others to a distance of about a mile; pumping 5,000,000 gallons a day for ten days lowered the head in wells one-fourth mile distant about 3 feet, and in wells one-half mile distant about 6 inches, while at a mile it was scarcely perceptible. This wide connection between wells leads to the conclusion that if a large well is opened on ground a little lower than those now flowing it is very liable to draw down

the water level and perhaps stop the flow in wells for some distance around.

If reports concerning a decrease in the supply at Albion are correct, it would seem that the wells in rock are supplied from a catchment area close at hand, for they are said to become weaker in dry weather, when the ground-water table in the surrounding region is lowered. Dr. A. C. Lane mentions a shortage in the Albion wells in July, and a cessation of the National Bank well in that city in dry weather.[a] The hardness of the water is such as to favor the view that it is taken from the overlying drift deposits. The head displayed by this water, like that from wells in the drift, may depend entirely on the height of the water table in the drift deposits in the region adjacent to the valley.

Several analyses of flowing wells at Albion and Battle Creek have been made. Those at Battle Creek are from the prospective waterworks wells and were made at the hygienic laboratory of the University of Michigan. Those at Albion are from wells 100 feet or more deep, and were made by Delos Fall, of Albion College.

Analyses of sandstone waters.

[Parts per million.]

	1.	2.	3.	4.	5.	6.	7.
Iron	.....	.....	.....	.....	.....	2.5	4.0
Chlorine	36.88	4.5	4.5	5.6	13.2	8.0	8.0
Sulphuric acid	.....	.....	.....	.....	33.59	Trace.	Trace.
Hardness	307	293	293	243	250	230	230
Total solids	386	309	305	232	385	290	310

1-4. Albion. 5-7. Battle Creek.

The iron in the Battle Creek waters will stain crockery ware placed under the flow. The presence of the iron is thought to lead to a clogging of pipes by organic growths (*Crenothrix*, etc.), and keep the supply below the original estimates from flows made when the wells were sunk. The hardness is largely temporary in the Battle Creek waters.

WATER SUPPLIES OF JACKSON COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Jackson County, like Calhoun, has a large amount of loose-textured drift both in moraines and in gravel plains, and also is like Calhoun County in being underlain by Marshall sandstone. In part of Jackson County other sandstones of Carboniferous age, which are large water-bearers, overlie the Marshall sandstone. The gravel plains are

[a] Ann. Rept. State Geologist for 1903, p. 103.

extensive in the eastern half of the county, but in the western half the glacial drainage was restricted to channels running among the moraines. In the southwestern part of the county sandstone hills, rather than drift deposits, give the surface its inequalities. Elsewhere the knolls and ridges are principally of drift. Rock, however, is within easy reach of the drill all through the county, and wells in rock are very common on the farms as well as in the villages.

About three-fourths of the county, chiefly the northern and south-central portions, is drained by Grand River and its tributaries, Portage River and Sandstone Creek. The southwestern part of the county is tributary to Kalamazoo River, and a small area in the southeastern corner to Raisin River. The drainage is thus chiefly toward Lake Michigan, only that of the Raisin being to Lake Erie.

Good wells are ordinarily obtained at depths of 25 to 50 feet, but in the sandstone hills in the southwest part of the county they are often 75 to 125 feet or more, and have but little rise of water.

WATERWORKS.

JACKSON.

The city of Jackson, with a population of about 25,000, is near the geographic center of Jackson County, and is the only town in the county having waterworks. The plant was built in 1870 and is owned by the city. The wells and pumping station are in the valley of Grand River, in the south part of the city, at an altitude about 930 feet above tide, and the wells are distributed over a length of three-fourths of a mile. The supply is from twelve wells drilled into sandstone and ranging in depth from 200 to 400 feet. Eight are 10 inches and four 8 inches in diameter. The water stands only 2 to 6 feet below the surface. Its underground course is northward, for heavy drafts at the pumping station have more effect on wells to the north than on wells located in other directions from the pumping station. The wells, as stated by the engineer of waterworks, are capable of yielding about 6,500,000 gallons a day when siphoned at a level 17 feet below the natural head, or 19 feet below the ground at the pumping station. The average daily consumption, however, is only about 2,000,000 gallons, and the highest less than 5,000,000 gallons. The temperature of the water in the collecting basin November 25, 1905, was 50° F. At the pumping station are two Holly pumps, one with a capacity of 4,000,000 gallons, the other of 8,000,000. The distribution system at the time of the last annual report, February 28, 1905, embraced about 64 miles of mains, with 3,963 taps and 564 fire hydrants. The ordinary pressure is 60 pounds per square inch, and the fire pressure 80 to 100 pounds. The cost of the plant was approximately $500,000, but the precise figures are not available.

The income is $35,000 and the running expenses, including fuel, $12,000 a year.

The State penitentiary, located within the city limits of Jackson, has a water supply independent of the city system. The source of supply for boilers is Grand River. For all other purposes water is pumped from wells in sandstone located on the prison grounds. The number of inmates supplied is about 700 and of free employees about 100.[a]

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Jackson County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Brooklyn	494	980	Drilled wells; mill pond.	25 +185	10	185	60	40	+2 −10	Small.
Clarks Lake	56	976	Drilled wells; mainly from rock.	40	22	18	40	40	+7 −2	Do.
Concord	534	1,010	Drilled wells; Kalamazoo River.	40	60	90	75	65	−30	Large.
Devereaux		995	Open and driven wells.	40	25	85	30	30 80	−20	Small.
Francisco	125	1,014	Driven wells		20	45	40	40	−14	None.
Grass Lake	648	1,000	Wells and lake	60	20	85	60	60	−18	Small.
Hanover	378	1,122	Drilled wells	50	80	100	80	80	−80	None.
Horton	250		do	75	50	100	60	60	−35	Large.
Napoleon		964 980	Driven wells	0 30	7	210	30	30	−2 −16	Small.
Norvell		942	Driven wells; Raisin River.		15	75	35	35	−15	Do.
Parma	420	983	Open and driven wells	0 40	25	75	35	35	−20	Do.
Pulaski		±1,094	Drilled wells	15	80	120	100	100	−80	None
Rives Junction		920	Driven wells	60	25	150	100		−10	Small.
Spring Arbor		±1,000	do	30	30	75	60	60	−25	Large.
Springport	559	990	do	35	30	60	60	60	−35	Do.
Waterloo	50	950	do	50	20	200	50	50	−20	Do.

FLOWING WELLS.

Flowing wells are obtained at several places in the county, usually from rock, as indicated below.

JACKSON.

Wells similar to those at the waterworks are not uncommon in the city. Some of the earliest ones made between 1865 and 1885 had sufficient head to flow about 10 feet above Grand River, but the head has been gradually lowered with the increased demands made on the water beds. The prospects for a long-continued supply, however, are good, for the lowering of head thus far amounts to but a few feet, and the loose-textured sandstone in which water is found transmits it with sufficient rapidity to prevent even temporary exhaustion by pumping. It is probable that flows could be obtained along Grand

[a] Information furnished by the warden, A. H. Armstrong.

River and its tributaries in the northern part of the county by pene-
trating the Marshall sandstone, and possibly they could be obtained
in the drift deposits. So far as known no such wells have been made
in this vicinity, though they have been obtained to the north in adja-
cent parts of Ingham and Eaton counties, at Leslie, Onondaga, Wi
field, and Eaton Rapids.[a]

The character of the water from this sandstone is excellent, bein
sufficiently soft, as a rule, for laundry use or boiler use, and free fro
all surface contamination.

NORVELL-BROOKLYN-CLARKS LAKE DISTRICT.

Flowing wells have been obtained on low ground along Rais
River and its tributaries, both in Norvell and Columbia townshi
from near Norvell to Clarks Lake. They are either from sandsto
or at the base of the drift.

The easternmost well noted is on the farm of J. M. Horning in s
13, Norvell Township (T. 4 S., R. 2 E.). It is on the edge of a swam
standing about 940 feet above tide or 100 feet lower than Mr. Hor
ing's residence. It is 95 feet in depth and entered a blue rock at
feet which yields a weak flow that will rise 4½ feet above the surfa

L. M. Greene, of Brooklyn, has a well 41 feet deep and 3 inches
diameter, made in June, 1902, which flows about 3 feet above t
surface. The water is chalybeate.

George C. Greene has two flows 30 and 40 feet deep which str
sandstone at 29 to 30 feet. They penetrate about 10 feet of surfa
gravel, then a bed of blue clay, below which is another gravel b
resting on the sandstone. They flow about 1 gallon a minute a
have a temperature of 52° or 53° F.

At the railway station in Brooklyn a well 45 feet deep strikes
stone near bottom and water rises about level with the

G. M. Barstow, of Brooklyn, has a we
1½-inch stream from a 2-inch pi
feet.

Clyde Beckwith, of
railroad station t
head of 13 feet

There ar
east fro
is scar
low

l owned by Dr. W. W. Lath
reaching the rock. It is
d has a head of 7 feet above
ike, only 10 feet from the wa
nixed clay and gravel, and the
gravel. A strong stream gush
ith of the well. After tw
at reduced, was restored
into the well.
is a flow about a mile
d running to Cement City
vestward from Grand River
River, and thus is on the
rie. The wells in Clarks

vater in the wells around Clarks
the wells terminate in sand
lcareous material, there is a
water from the drift fills the
ng the depressions in which the
ve a water table in the drift
wells. The following data
tained by Mr. Udden in 19
. Beach; 3-inch well, 61 feet deep
t 59 feet; flow 33 gallons a minute
ard, sulphurous, and chalybeate
lic ram.
F. Loeb; 1½-inch well
ne; water chalybeate
te.
Cooper; 2-inch well
flows 12
Gra

of
er
are
the
hese
south
s deer
of salt.
its place
rds from
nt within
eet without
discouraged
he salt spring
probable that
containing salt.
er of such salinity
The spring still dis-
after the test boring
a large volume of fresh

River and its tributaries.

WATER SUPPLIES OF WASHTENAW COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Washtenaw County, of which Ann Arbor is the county seat, has a great diversity of surface, ranging from the sharpest of morainic knolls to very flat old lake bottom. A prominent morainic belt with accompanying outwash gravel plains occupies the western range of townships and swings eastward across the northern edge of the western half of the county. It is dotted with lakes, many of which are held in deep basins among sharp knolls. The wells in this region are often sunk to depths of 100 feet or more. East of this morainic belt is a tract of 150 square miles or more in which the surface is gently undulating and largely of loose-textured till in which wells are generally shallow. This is succeeded on the east by a prominent morainic belt that runs from the northeast to the southwest corner of the county and occupies a strip 4 to 6 miles wide. In this belt wells are frequently 100 to 150 feet, and occasionally 250 feet in depth, though wells 50 feet or less in depth are not uncommon, and in the southwestern part are generally shallow. East of this morainic belt is a sag which was utilized largely as a line of glacial drainage outside or west of a later moraine, known as the Defiance moraine. The wells are generally shallow along this sag. On the Defiance moraine they frequently reach depths of 100 feet or more in the northeastern part of the county, but are generally shallow from Huron River southwestward. Immediately east of this moraine the lake plain sets in which extends eastward to Lake Erie. The elevation of its western edge is about 800 feet, but drops to less than 650 feet in the southeastern part of the county. This lake plain is largely covered with gravel and sand in Ypsilanti Township and southward to the county line, but is mainly clay elsewhere. The wells are ordinarily shallow on the sandy tracts, but on the clay they reach depths of 100 to 150 feet in many instances, this being about as difficult a region as any in the county in which to obtain shallow wells. It is on the clay in the southern part of the county that the flowing wells of part of the York district occur, which are discussed in connection with those of Lenawee and Monroe counties (pp. 82–86).

The use made of flowing wells in this county is probably as great as in any in the State. Aside from the large flowing-well district that extends from York and Saline townships into Lenawee County there are strong flowing wells at Ypsilanti supplying the waterworks and at and near Ann Arbor supplying the waterworks and a few family wells. Another strong supply is on the Steere celery farm 4 miles south of Ann Arbor, and in the district extending thence

nearly to Ann Arbor. There are a score or more of flowing wells in the village of Manchester, and a small district with strong flows midway between Manchester and Chelsea. In addition to these as indicated below are scattered flows in valleys on low tracts at several points within the county.

Springs are a conspicuous feature in much of the county, and together with general seepage give to the streams a strong dry-weather flow. The map of the Ann Arbor quadrangle[a] shows the effect of marsh land along the drainage lines. The head produced by the accumulation of water in the moraines causes a marshy condition of the valleys by the continual seepage, and from the marshes the streams are fed. The utilization of springs in the vicinity of Ann Arbor has been considerable, and is treated in the discussion of the supplies of that city. The springs are generally of fresh water with but little sulphur or iron. There are, however, a few that are highly mineralized and produce a coating on objects over which the water flows. An occasional salt spring is reported. One of these gave the name to Saline village and river; it is located just south of the village in the valley of the river and was a conspicuous deer lick and was also used by the Indians in the manufacture of salt. It gushed up from considerable depth and built a mound at its place of discharge. A boring was sunk many years ago a few yards from the edge of the spring to determine if salt beds were present within convenient depth to mine. The boring was carried 150 feet without reaching the bottom of the drift, and the drillers became discouraged and abandoned it. Although only a few yards from the salt spring this boring struck a strong flow of fresh water. It is probable that the salt water found its way up from the rock strata containing salt, for the drift can scarcely be supposed to yield water of such salinity as this spring is reported to have possessed. The spring still discharges but is said to have become much fresher after the test boring was made, probably through the inflow of a large volume of fresh water opened by the boring.

This county is chiefly drained by Huron River and its tributaries, but the southern part is drained by Raisin River, and the northeastern by River Rouge, while a few square miles on the western border are drained by Grand River. The Huron flows through Dexter, Ann Arbor, and Ypsilanti, and may eventually be utilized to supply the waterworks of these places. The village of Manchester may take a public supply from Raisin River, though the flowing-well conditions there are such as to encourage development for a public supply. Saline River, a tributary of the Raisin, may be utilized for public supplies by the villages of Saline and Milan, which have not as yet been able to find an adequate supply from wells to warrant

[a] Obtainable in separate form from the United States Geological Survey, price, 5 cents.

building a waterworks plant. Milan now has fire protection from Saline River, the pumping being done at the electric light plant.

The supplies from rock in Washtenaw County are generally poor because of the salinity of the water. Some of the wells in the southern part of the county, however, obtain a fresh water and so do wells in the northwestern part, the former from limestone and the latter from the Marshall sandstone. The Coldwater shale, which immediately underlies the drift, in a considerable part of the county yields very little water and that is usually salt.

Wells that penetrate the black Devonian shale in the southeastern part of the county often strike gas, in some cases in amounts sufficient to justify piping to dwellings for light. The gas is in some cases found in beds of sand and gravel that overlie the rock. The occurrence of gas has led to the organization of a company to drill in and near Ypsilanti for gas and oil, not only in the Devonian shale but also to lower horizons. Several deep borings have been made in Ypsilanti, two at Ann Arbor, and one at Milan, none of which found anything of value but salt water after entering the rock and casing out the fresh water found in the drift. Some use has been made of the salt water for baths at two of the deep wells in Ypsilanti. Water from a depth of 930 feet in the well on the University Campus at Ann Arbor was found to contain about 13 per cent of salts as follows, the analysis being made under the direction of Prof. E. D. Campbell of the University:

Analysis of brine in campus well, University of Michigan, Ann Arbor.[a]

	Parts per million.		Parts per million.
Sodium (Na)	30,008.98	Sulphate radicle (SO_4)	11,524.3
Magnesium (Mg)	3,121.01		
Calcium (Ca)	13,464.07		128,805.C
Chlorine (Cl)	70,686.64	Saturated with hydrogen sulphide.	

ANN ARBOR.

GENERAL SUPPLIES.

The city of Ann Arbor, county seat of Washtenaw County, and seat of the State University, is located on Huron River 35 miles west of Detroit. There is strongly morainic topography in and around the city, and between the moraines are lines of glacial drainage filled with gravel and sand. These deposits of gravel and sand lie above the present river level and rest upon beds of till. Wells are obtained in them at depths ranging from 15 to 80 feet. Numerous hillside springs occur at the junction of the gravel with the underlying till, and at the borders of the moraines. Several of these springs

[a] Expressed by analyst in percentages and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

A. TYPE OF DRILLING APPARATUS USED AT YPSILANTI AND VICINITY.

B. BONSTEEL FLOWING WELL IN 1902.

Showing old wooden casing and size of stream thirty-two years after its completion. The original flow was a 3½-inch stream.

have been developed and one has been turned into the waterworks supply. There are also springs which appear to boil up through the till. In addition to the natural supplies from the river and from springs the city is favored with strong flowing wells, largely developed by the Ann Arbor Water Company, and other supplies from the glacial drift and its associated gravel and sand. Water from the rock formations beneath the city is found to be brackish and not suitable for drinking.

FLOWING WELLS.

The flowing wells, so far as developed, are in a recess in a moraine in the western part of the city. Subsequent to the withdrawal of the ice sheet this recess was occupied by Huron River, which at one time flowed southward from Ann Arbor. The river made a deposit of gravel and sand in this recess in the moraine. This deposit has been trenched by modern drainage, and the flowing wells are chiefly in these trenches. The shallower flows obtain their supplies at the base of this deposit of gravel and sand without entering till, but the deeper ones pass on through till to water beds associated with it.

The supply for the shallow wells is not entirely from water falling on the immediate borders of this recess, there being along the ravine in which they are located several springs which appear to rise from considerable depth, and which may be fed from sources more remote than the bordering slopes of the moraine. Observations on one spring, conducted through an entire year, showed a constant water temperature of 51° F.; thus agreeing very closely with the temperature of the deeper flowing wells. This seems to indicate that the water comes from a depth sufficient to be unaffected by seasonal temperatures and probably from as deep seated a source as that which supplies the wells which pass through till.

The wells first made passed through till and reached depths of 75 to 150 feet, the deepest being nearly down to bed rock. Several were in operation prior to 1895, when the Ann Arbor Water Company began an extensive development of the district. Some were located on the north side of West Huron street, on the old bed of Huron River or in a ravine trenched in it. Others were along a ravine two blocks south on the south side of West Washington street. The water company has developed only the latter strip, but by so doing has lowered the water table north of Huron street sufficiently to stop all the wells from flowing. The wells in the same ravine with the water company's wells are nearly all maintaining a flow, but much less vigorous than at first. When first made they discharged several gallons a minute from 2-inch pipes, but now only discharge 1 to 2 gallons a minute. The only private wells now in operation are one 80 feet deep on the Allmendinger property, a few rods northeast of the

waterworks pumping station; one 74 feet deep on the Hutzel property, a few rods north; and one on the Lutz property, 112 feet deep about one-eighth mile west of the pumping station. The Allmendinger and Lutz wells supply fish ponds and are also used for drinking. The Hutzel is used chiefly for drinking. The head of the Hutzel well is said to have been 22 feet when made about 1894, but is now only 5 feet. Part of this decrease is perhaps due to leakage around the pipe. The Allmendinger well, also made about 1894, is reported to have had a head of 20 feet, but now barely overflows. There is some leakage in this well which makes it impracticable to get the full head. Another well on the same property was so reduced after the water company wells were made that it was abandoned. The head in the Lutz well is only 3 feet, but no data have been obtained as to whether it was once greater. There is close sympathy between the Hutzel well and the water company's wells near it, for it is stated by the superintendent of the waterworks that almost immediately after the pumps are stopped and the flow of the water company's wells shut off this well increases its flow about one-third.

Temperature observations have been made monthly for a year on the Hutzel and Lutz wells. The former has been constant at 51° F.; the latter has only ranged from 50.8° to 51.1°, and this may be due to the effect of the atmosphere on the escape pipe.

WATERWORKS AT ANN ARBOR.

The supply furnished by the Ann Arbor Water Company was divided for a few years, from 1886 to 1895, between Huron River and a group of flowing wells and springs north of the city. But a prejudice against river water having arisen, the water company developed another tract of flowing wells within the city limits and thus made it possible to dispense with the use of river water except perhaps at times when the consumption is unusually great. It has built a second pumping station at the wells inside the city limits, and this station it claims now furnishes about three-fifths of the supply.

A reservoir with a capacity of 2,500,000 gallons was built in connection with the first pumping station and stands about 200 feet above it on the most elevated point in the city (about 1,000 feet above sea level); the second station supplies for the same reservoir. For fire protection the city has had only the reservoir pressure, which ranged theoretically from about 30 pounds per square inch in elevated residence parts of the city to 100 pounds on low ground along Huron River.

The distribution system when the works were put in operation had only 14 miles of mains, but with the growth of the city and increased use of the public supply the mains have been extended to about 40

miles. Nearly 30 miles are of cast-iron pipe from 16-inch down to 4-inch, and in the remainder wrought-iron pipe, chiefly 2-inch or less, is used. The size most extensively used is 6-inch, and the smaller sizes are being replaced by this size. At present there are about 2,400 private taps and 150 meters in use, which, together with water supplied to the city and to the university, called for a daily average supply in 1904 of about 1,800,000 gallons. There is an occasional demand in dry seasons for 3,000,000 gallons or more.[a]

Prof. I. C. Russell, in an examination made in June, 1905, for the city council of Ann Arbor, determined the present condition of the wells of the water company as follows:

Station 1 (in Huron Valley): One tank well 25 by 30 feet, gravel bottom, brick lined, with four tubular wells in bottom (one 2-inch and the others 6-inch), extending to about 120 feet from the surface of the ground, which discharge into the tank well; a collecting gallery or trench which originally had in its bed several tubular flowing wells 60 to 120 feet in depth, of which only three are now flowing; one 6-inch well 100 feet deep, from which water is pumped for condensing purposes and then turned into the city supply;[b] one dug well, about 8 feet deep, near the pumping station; two dug wells 9 feet deep fed by springs in a valley across Huron River; a 12-inch receiving pipe still connected with Huron River. The water pumped at this station in 1904 averaged 738,356 gallons daily, as shown by the books of the water company.[c]

At station 2 (in the western part of Ann Arbor) there are 57 wells in use which range in diameter from 2.5 to 8 inches. About 50 of these are driven past a bed of till into a water-bearing bed and have depths of 75 to 150 feet or more. The remainder obtain their supply from the surface sand and gravel at depths of scarcely 30 feet. Nearly all discharge into a large receiving well near the pumping station.

The manager of the water company claims to be able to get 1,700,000 gallons daily from this supply and to have averaged 925,000 gallons in the year 1904. To increase the supply at this second pumping station, water from White Spring, which issues from a hillside just west of the city limits, was connected in 1905 with the supply from wells. In addition to the fifty-seven wells now in use there are several wells that are clogged, apparently by precipitates on their strainers.

Means for estimating the prospects of this supply are not adequate enough to justify a positive statement. It is merely known that the head in private wells near by in the same ravine with those of the water company has fallen from about 22 feet above the surface to less than 5 feet, and that wells on adjacent higher ground have ceased flowing. The latter wells, however, appear to stand fully as near the surface in 1905 as they did in 1902, thus indicating that the process of lowering is at a standstill.

[a] Data furnished by A. K. Hale, manager of the water company.

[b] The original supply for condensing purposes was drawn from Huron River, and the superintendent of the waterworks states that the intake pipe is still in place; also that there are two other wells that may be drawn upon for condensing purposes.

[c] The superintendent estimates that 90 per cent of this amount comes from the tank well and the collecting gallery, and scarcely 10 per cent from the wells used for condensing purposes.

The shallow wells supplied by water not confined by clay or other impervious bed are reported to pass through a few feet of peaty material, then fine sand saturated with water, to a coarser sand or fine gravel at bottom, resting apparently on the surface of the till. The sand being relatively slow to transmit water compared with the gravel beneath, it acts virtually as a cover to the water flowing through the gravel, so that the water working through the gravel from higher tracts to the west has sufficient head to rise in the pipes and overflow when borings are sunk to it, just as is done by the deeper-lying water under the till.

The wells which pass through till into lower water beds show sections that differ widely in structure, there being in some a considerable thickness of water-bearing material interbedded with the till, while in others the till is a nearly unbroken sheet from the surface down to the rock. The weak wells are at points where the water beds in the till are very thin or are wanting. The strong wells are at points where there is a good development of gravel or coarse sand in the till. The till itself is not uniform, the upper part being a soft adhesive blue clay, while the lower part is a hard or partly cemented clay thickly set with stones and apparently of greater age than the overlying soft clay. The water beds in wells 140 to 150 feet or more in depth are interbedded with the hard clay or lie at the base of the drift series.

Analyses of water.—The following analyses from each pumping station were made at the chemical laboratory of the University of Michigan in June, 1905, under the direction of Prof. E. D. Campbell:

Analyses of water from Ann Arbor pumping stations.

	Parts per million.		Per cent of total solids.	
	1.	2.	1.	2.
Carbonates (CO_3)	175.2	166.1	38.87	39.97
Sulphates (SO_4)	96.9	76.8	21.49	18.48
Chlorine (Cl)	3.7	8.5	.82	2.05
Nitrates (NO_3)	.4	.12	.08	.02
Calcium (Ca)	115.6	105.3	25.65	25.34
Magnesium (Mg)	27.8	30.8	6.16	7.42
Sodium (Na)	4.7	4.2	1.04	1.01
Potassium (K)	5.6	4.9	1.24	1.18
Silica (SiO_2)	17	16.2	3.77	3.88
Alumina (Al_2O_3)	1.6	.6	.36	.19
Ferric oxide (Fe_2O_3)	2.3	1.9	.52	.46
	450.8	415.6	100	100
Specific gravity	1.0006	1.0006	.....	.....
Total solids found	491.9	450.2	.....	.....

Sample No. 1, Ann Arbor water pumping station No. 1, known as upper station; composite sample from all wells at this station. Sample No. 2, Ann Arbor water pumping station No. 2, between Washington and Liberty streets, known as lower station; composite sample from all wells at this station. The spectroscope gave no test for strontium and lithium. No nitrites were found. The difference between the total solids found on evaporation and the total solids in columns 1 and 2 is water of crystallization, in large part due to the formation of gypsum ($CaSO_4.2H_2O$). The water was clear when collected, but upon standing became cloudy, owing to the escape of the carbon dioxide (CO_2) and the formation of calcium carbonate ($CaCO_3$). Almost all the salts in the water will form scale in boilers, but the water would be much improved by softening with sodium carbonate (soda ash), either alone or in conjunction with calcium hydroxide (milk of lime).

Sanitary analyses have been made at frequent intervals at the hygienic laboratory of the University of Michigan. The water has been found safe for drinking, except when surface water has gained access to the supply, and Dr. V. C. Vaughan, the director of the laboratory and dean of the medical school of the university, states that in the twenty years since the waterworks has been in operation he has learned of no case of disease that can be referred to contamination of this water supply. The sanitary surroundings of the shallow wells, however, is such that their use should be discontinued.

WATERWORKS.

YPSILANTI.

The public supply at Ypsilanti is from a group of flowing wells in the Huron River Valley in the southeastern part of the city. The location seems an unwise one, since the city, with all its contamination by cesspools, naturally drains past the waterworks plant. The plant might easily have been located above the city, and thus have avoided this chance for contamination. The wells are 60 to 80 feet in depth and obtain water from gravel below a blue till. The head is sufficient to cause the water to rise only a few feet above the surface. The wells made prior to 1904 are situated around and discharge into a large receiving well, from which water is pumped to a water tower 190 feet above the wells and 75 feet above the high ground in its vicinity. The supply from the flowing wells became inadequate in 1903, but new wells were added in 1904, which, by heavy pumping, yield enough to meet the present demands.

The following section of one of the wells made in 1904 was furnished by the driller, W. J. Richards:

Record of well at Ypsilanti waterworks.

	Thickness.	Total.
	Feet.	*Feet.*
Surface material	8	8
Hard stony clay	28	36
Gravel with water, rather muddy	2	38
Hard stony clay	4	42
Gravel with artesian water	26	68

Diameter of well, 8 inches; cost, $2.25 per foot; flow, 25 gallons a minute; head 4 feet above surface, or 685 feet above tide; temperature, 51.5° F.

It may be thought that the addition of new wells from time to time may keep the city supplied. The water is chalybeate and hard, but is of pleasant taste. The chances for contamination depend on the protection offered by the clay cover against the access of the city drainage.

CHELSEA.

The water supply of Chelsea is from about 20 wells, 20 to 25 feet deep, arranged in an L-shaped system on a low tract in the northern part of the village. The water rises about to the surface, but is pumped. This system was put in operation in 1899. Prior to that time some 6-inch wells were in use, which not being properly protected became clogged with sand. It would seem wise to substitute for the present supply one outside the thickly settled part of the village.

Several deep wells in the village obtain supplies from rock, which is struck at 90 to 110 feet. A village well 90 feet deep near the center of the business part of town is provided with a pump, and is utilized extensively.

The following partial analysis, furnished by M. O. Leighton, of the United States Geological Survey, shows the character of the city supply at Chelsea. The water seems to be satisfactory for domestic purposes, but gives much trouble in boilers, and creek water has been pumped for this purpose:

Partial analysis of well water at Chelsea.

	Parts per million.
Color	32
Iron (Fe)	Trace.
Clorine (Cl)	12.5
Carbon dioxide (CO_2)	147.92
Sulphur trioxide (XO_3)	110

S. J. Lewis, analyst. Depth, 18 feet.

VILLAGE SUPPLIES.

DEXTER.

The village of Dexter has no waterworks system, the residents depending chiefly upon shallow dug wells, so that chances for contamination are very great. These wells in many cases are surrounded by privy vaults and stables. There are a few driven wells in the business part of town of shallow depth—30 feet or less—which are perhaps less liable to contamination than the dug wells, though not above suspicion. On the high ground in the southeast part of the village there are deeper wells, two of which have been driven into the rock and obtain a fresh supply said to be from sandstone. Inasmuch as there are abundant supplies of good water both underground and in the streams in the vicinity of this village from which a public supply might be obtained, there would seem to be no sufficient excuse for continuing the use of the shallow wells inside the village limits.

SALINE.

Saline has no waterworks system. Many of the wells are dug 35 to ; feet deep, but those in the northern part of the village are shal- wer. There are a few driven wells in the northeast part about 75 et deep which are said to strike water which rises much nearer to the ırface than in neighboring dug wells 40 to 50 feet deep.

MILAN.

There is only fire protection at Milan, and some difficulty is found in ›taining a supply suitable for domestic use. Several wells are driven › depths of over 100 feet. There are a few shallow flowing wells in ıe low ground along Saline River on the Monroe County side of the llage, which are discussed in connection with the Milan-Cone flow- g-well district (pp. 27–29). The village is a thriving town, and should ıve a waterworks system as soon as an adequate supply can be found. ›ssibly it will need to use river water, though this seems a poor sup- y except for fire protection and sprinkling, as the stream becomes w and foul in dry weather.

In the table below are given a number of partial analyses of well ıters in the vicinity of Milan, the data being furnished by M. O. ›ighton, of the United States Geological Survey. The waters, as dicated by the percentage of CO_2 are not very hard, for in most aters examined in Michigan it exceeds 130 parts per million. The ıalysis of the rock water from the Whitmarsh well is of interest for ırposes of comparison:

Partial analyses of well waters near Milan.

[Parts per million.]

	1.	2.	3.	4.	5.
olor	42	19	46	51	14
ron (Fe)	2	Trace.	Trace.	2	Trace.
hlorine (Cl)	9	59	21.2	9	14
'arbon dioxide (CO^2)	94.18	121.36	108.87	122.15	64.81
Sulphur trioxide (SO_3)	−29	185	113	−29	−29
Hardness (as $CaCO_3$)	+139	.....	.....	.....	.....

S. J. Lewis, analyst. 1. Throop, depth 116 feet. 2. Whitmarsh (rock), depth 144 feet. 3. Whitmarsh, depth 412 feet 4. Reves, depth 40 feet. 5. Wardlop, depth 62 feet.

FLOWING WELLS.

PITTSFIELD JUNCTION DISTRICT.

In the old valley of Huron River leading south from Ann Arbor is a ›elt of flowing wells which has its chief development near Pittsfield unction (T. 3 S., R. 6 E.), on the celery farm of J. B. Steere. Most f the wells are shallow, the average depth being about 28 feet, and the reatest 48 feet. They usually penetrate a few feet of peat, beneath hich is a bed of clay, apparently a lake or stream sediment, which forms

the cover to the coarser material yielding the water. This clay is limited to the low part of the valley, the borders of the valley having generally a thick deposit of gravel, which probably absorbs the rainfall and also the drainage from the bordering uplands, and thus supplies the flowing-well district.

Before wells were sunk in this valley strong springs gushed up at a few places, one of the strongest being on the celery farm. These springs are apparently from the same source as the wells.

The first well in this district was made on the Steere farm in sec. 10, Pittsfield Township, in 1887, and there have been about 20 wells driven by Mr. Steere, 16 of which are now in operation. They range in depth from 26 to 32 feet. Water rises in them 3 to 7 feet above the surface. The wells are on the divide between Huron and Saline rivers, at an altitude of about 820 feet, the highest ground being 823 feet. The underground flow apparently passes from the district where these wells are located southwestward along the line of glacial drainage, but the head decreases in that direction, so that wells a mile southwest of the celery farm lack 2 feet of reaching the surface. The flows between the celery farm and Ann Arbor are scattered, there being two in the southwest part of section 9, on land belonging to John Lawrence, one in the southeast part of the same section on the land of F. Tichnor, and two in section 4 on the land of H. Schwab.

Measurements of flow were made in August, 1904, as given in the table below. It is the opinion of the well owners that the flow is slightly less in dry seasons than in wet, but this has not yet been verified.

Rate of flow and temperature of wells in Pittsfield Junction district.

Location.	Flow per minute.	Temperature.
	Gallons.	°*F.*
Steere well at north house, east side of road, 4-inch pipe	45	[illegible]
Steere well at middle house, east side of road, discharge pipe 1½-inch	8.25	[illegible]
Steere well at south house, east side of road, discharge pipe 1½-inch	6	[illegible]
Steere well at house on west side of road, discharge pipe 1-inch	6.25	[illegible]
Steere well 200 feet southwest of last-named well, 2½-inch pipe	57.7	[illegible]
Well on west side of celery field, 3-inch [a]	110	[illegible]
Lawrence well, farthest west in sec. 9, discharge pipe ¾-inch	5.75	[illegible]

[a] About 4 feet from this well is a 2-inch well which draws from the same bed. When both wells flowed the 3-inch well yielded 90 gallons and the 2-inch 46 gallons a minute, or a total of 136 gallons. The 3-inch well when the 2-inch well was closed flowed 110 gallons, and the 2-inch well when the 3-inch was closed flowed 61 gallons. There is thus a gain of only 26 gallons per minute by the addition of the 2-inch well. These wells were measured by taking the height of the jet above the top of the pipe and calculating by the tables in Water-Supply Paper No. 67, page 92. Measurement of the first well in the above list was made by the rate of flow past a weir over which the water passes. The other wells were all measured by holding a 10-quart bucket under the stream.

Observations of temperature on five of the wells in this district at four different dates show that they are less steady than the deeper wells at Ann Arbor, as well as lower in average temperature. It is a matter of interest to know whether wells located in a swamp have a lower average temperature than those located on dry ground, where the surface heat can more readily penetrate to considerable depth.

Variations in well temperature in Pittsfield Junction district.

Well.	Temperature			
	June.	July.	August.	November.
	°F.	°F.	°F.	°F.
Lawrence, western well	48.9	49	49.4	50.8
Lawrence, eastern well	49.8	49.8	50	50
Steere, well at north house	50	50	50	49.5
Steere, well at middle house	49.8	49.8	49.6	49.5
Steere, well at south house	49.3	49	49	49.5
Steere, well at west side of celery field			49.3	49.3

An analysis of the water at the north house on the Steere celery farm was made at the hygienic laboratory of the University of Michigan for the purpose of ascertaining its purity as a water supply.

Sanitary analysis of Steere flowing well near Pittsfield Junction.

	Parts per million.
Total residue	295
Sodium chloride	7
Nitrates	Trace.
Nitrites	None.
Free ammonia	0.0106
Albuminoid ammonia	.025
Hardness	178.57

SHARON TOWNSHIP.

Several flowing wells have been obtained in the northeast part of Sharon Township (T. 3 S., R. 3 E.) at the eastern base of a prominent moraine that occupies much of these townships. They are chiefly in the recesses in the moraine from which the headwaters of Mill Creek flow. (See fig. 18.)

Several of the wells have a discharge of about 8 gallons a minute, and one discharges more than a barrel a minute. Six have been fitted with half-inch reducers in order to lessen the flooding caused by the overflow. The deepest well reported is 70 feet, and several are about 50 feet. The water is hard and strong in iron. Possibly rock is struck at the bottom of some of the wells.

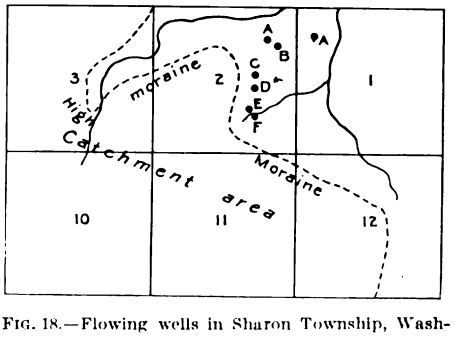


FIG. 18.—Flowing wells in Sharon Township, Washtenaw County.

This district can probably be extended westward along the line of Sharon and Sylvan townships up a valley, and possibly eastward a short distance into the plain east of this moraine. It is probable also that along Mill Creek Valley northeastward and along some of its tributaries flows can be obtained. Indeed, two wells on tributaries of Mill Creek have been reported to flow, but

were not visited. One is on the Spaulding farm, 2 miles south Chelsea, and the other on the Fletcher farm, 2½ miles southeast Chelsea.

Wells at Sharon.

Letter on fig. 18.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Te pr tu
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	
A	1	M. Kusterer	1901	2	70	937	939	8	
A	2	J. Houck	1900	2	54	930	938	8	
B	2	do		2		930	932	8	
C	2	J. Meyers		2		930	932	8	
D	2	do		2		930	932	8	
E[a]	2	F. Everett (house)		2	55	930	932	75	
		F. Everett (barn)		2	62			75	

[a] At the time of Leverett's visit in 1899 Mr. Everett had two flowing wells, each discharging a 75 gallons a minute from a 2-inch pipe; in 1904 these were found by Mr. Udden to be under control supplied with faucets. The house well terminated in gravel, but the barn well, which is 57 feet d went through 2 feet of hard material at bottom, suspected to be Marshall sandstone. Sandstone reached in a well 1½ miles southeast in sec. 7, Freedom Township, at only 54 feet depth, and penetr 48 feet, leaving no doubt as to its identity.

MANCHESTER DISTRICT (T. 4 S., R. 3 E.).

In the village of Manchester, on Raisin River in the southwest part of Washtenaw County, are about 20 flowing wells 28 to 60 deep, all from the drift. The shallowest is on the lowest grou but several on the highest ground at which flows are obtainable (feet above tide) are less than 40 feet in depth. The wells occu both sides of Raisin River at levels 10 to 25 feet above the stre The oldest well, that of W. Brighton, made in 1876, has been clog and its water now stands about 1 foot below the surface. A made in 1883 is still flowing, but with reduced head. Wells m in 1884 are still flowing with about the original strength, and so most of the wells made within the past twenty years. In two c weak wells are reported to have increased slightly in strength. flows range from about 1 quart a minute up to 6 gallons.

The water contains enough hydrogen sulphide to be readily tected by the odor in most of the wells. This is probably produ by the decomposition of pyritiferous material in rocks include the drift. Iron is also conspicuous in most of the wells.

The catchment area for this district is immediately north and of Manchester, in the gravel plain and morainic hills, which reac altitude about 100 feet above the highest flowing well.

Very little prospecting for flowing wells has been done in neighboring part of Raisin River Valley, but it seems probable flows could be obtained along the valley for some miles below M chester.

The flows thus far have proved inadequate to furnish a wa works system in Manchester, the population of the village being al 1,200, but it is possible, if not probable, that large wells sunk to

water-bearing beds at 35 to 40 feet might give a sufficient amount. Raisin River, however, furnishes a suitable and convenient source for a public supply.

Wells at Manchester.[a]

Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Cost.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	° F.	
S. J. Thorn[b]	1901	1.25	39	890	891	6	51.5	$11
W. Hensen[c]	1883	2	37	887	890	2	51	22
M. Traub[d]	1900	1	38	898	899	.75	52	28
G. W. Kief	1886	1.25	60	897	898	1	52	21
German Lutheran Church	.....	2	40	897	898	.75	52	.....
H. Pfuffle	1902	1.25	36	892	893	2	51	20
G. Goodyear	1884	1.5	40	894	895	.75	52	20
Geo. Roller	1899	1.5	40	894	894	1	51	.....
W. Brighton[e]	1876	3	38	895	894	1	52	.....
F. P. Maginn	1888	1.5	57	897	898	1	52	.....
Baptist parsonage	1899	1.5	40	897	898	1	51	30
C. Marx[h]	1890	1.25	40	892	891	.75	52	22
C. Staebler[g]	.....	1.25	40	892	893	.5	52	.....
M. Scheible	1884	2	35	888	890	3	.....	10
Mr. Staebler[g]	.....	1.25	40	892	893	.25	52	.....
Hildinger & Bowler	1898	2	35	890	890	3	52	.....
William Neubling	1893	2	38	900	900	1.5	52	10
J. Miller	.....	2	38	900	900	.....	52	.....
Mr Kemble	.....	2	28	885	889	4	52	.....
Manchester Canning and Packing Co.[h]	1902	2	40	890	895	5	52	40

[a] Data collected and arranged chiefly by Jon A. Udden.
[b] Has to be sand pumped once a year. Iron present in large quantity; also sulphur. Original water elevation, 896 feet.
[c] Original water elevation, 898 feet. Large amounts of iron and sulphur. Sandy soil, 6 feet; blue clay, 27 feet; red hardpan, 1 foot; gravel and sand, 2 feet.
[d] Flow is less in dry weather than in wet. Iron and sulphur present.
[e] Well used to flow at surface, but has not been properly cared for. It was the first flowing well put down in the town.
[f] Flow decreased by sand clogging.
[g] Flow decreased by clogging.
[h] Used for boilers; iron and sulphur present.

Below are given a number of partial analyses of waters from Manchester, the data being furnished by M. O. Leighton, of the United States Geological Survey. The deeper waters are considered satisfactory, but the shallow water at the livery barn and elsewhere shows evidence of contamination.

Partial analyses of well waters at Manchester.

[Parts per million.]

	1.	2.	3.
Color	19	46	36
Iron (Fe)	Trace.	Trace.	2.5
Sulphur trioxide (SO_3)	50	63	−29
Chlorine (Cl)	19	9	1.5
Carbon dioxide (CO_2)	58.92	76.07	47.93
Hardness (as $CaCO_3$)	+139	.....	.....

S. J. Lewis, analyst. 1. Livery barn; depth, 20 feet. 2. Freeman House; depth, 70 feet. 3. Dwelling; depth, 36 feet.

WATER SUPPLIES OF ALLEGAN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Allegan County fronts on Lake Michigan in the third tier of counties from the southern end of the State. It is drained chiefly by Kalamazoo River and its tributaries, but the southwestern part discharges through Black River into Lake Michigan at South Haven. The southeastern part is on the Kalamazoo moraine, but most of its eastern border is a gravel plain that lies between the Kalamazoo and Valparaiso morainic systems.

The outer member of the Valparaiso system rises but little above the gravel plain, but forms, with the plain, a catchment area for flowing-well districts west of it, between its outer and inner members. Its inner member traverses the central part of the county from north to south. West of it are sandy plains known as the pine plains, which cover about five townships. West and north of these plains is a clayey till ridge, which in the south fronts on Lake Michigan, but farther north bears away from the lake. On its inner or northwestern slope, in northwestern Allegan and southwestern Ottawa counties, flowing wells have been obtained at several points.

In the gravel and sand plains of Allegan County the wells are of shallow or moderate depths, 20 to 50 feet, but on the moraines they frequently reach depths of 100 feet, and occasionally 200 feet or more, though wells of moderate or even shallow depths are not uncommon. The flowing wells in the till plains are often 100 feet or more in depth, but usually wells that do not flow are much shallower. There are very few wells that have reached rock, the drift being from 90 to 300 feet or more in depth.

WATERWORKS.

There are public water supplies in Allegan, Plainwell, and Otsego though the supplies at the two last are only for fire protection and sprinkling, private wells being used for drinking and general domestic supply.

ALLEGAN.[a]

The public supply of Allegan is pumped from a well on the bank of Kalamazoo River. It is 37 feet deep and 24 feet in diameter The works were installed in 1872, and have cost about $100,000 to date. There are 11 miles of mains, 89 hydrants, and about 800 taps The average consumption is about 700,000 gallons, and the pumps have a capacity of 3,000,000 gallons.

[a] Data collected by Jon A. Udden.

OTSEGO AND PLAINWELL.[a]

ch of these villages pumps its public supply from Kalamazoo r, the water being pumped direct to the mains with the pressure l for in the case of fire, which at Otsego runs as high as 180 ds.

MISCELLANEOUS VILLAGE SUPPLIES.

ıe data on village supplies presented in the following table were ined chiefly by correspondence with residents of the respective ges:

Village supplies in Allegan County.

›wn.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
ı.....	2,667	650 710	Waterworks from driven wells.	240	.....	.....	.....	.....	+ 2	
yn.....	.....	789	Driven wells.....	170+	80	174	(a)	(a)	+ 10	
.....	200	661	.....do.....	.....	10	30	20	.....	+2-10	
.....	250	703	.....do.....	.....	15	30	20	20	− 4 − 6	
ıss.....	444	610 630	....do.....	.....	30	60	(?)	(?)	(?)	
ng.....	.....	672	.....do.....	.....	16	65	25	25	− 16	
augatuck	.....	734	Open wells..... Driven wells.....	.....	10	220	10 100-120	(?)	− 8 − 12 − 15 or lower.	
ille.....	454	662	Tubular wells...	225	5	120	30	30	.....	
ton.....	.....	640	No report.....	.....	.....	.....	.....	.....	.....	
·ds.....	50	727	Driven wells.....	.....	40	75	(a)	(a)	− 20	
r.....	150	740	Wells and stream	.....	20	40	30	25	Surface	
ns.....	400	712	Driven wells.....	.....	16	100	16	16 18	− 2 − 6	
.....	25	647	.....do.....	.....	14	160	60	60	− 8	
ı.....	300	837	.....do.....	.....	30	200+	30 40	30	− 30	
›.....	150	808	.....do.....	.....	25	120	40	.....	− 60	
tichmond	75	592 605	....do.....	.....	12	100	.....	(a)	(?)	
·orners...	.....	750	.....do.....	90	30	90	(a)	(a)	− 10	
o.....	2,073	718	Open and driven wells and river.	.....	20	20	20	20	− 15	
well.....	1,318	720 750	....do.....	.....	15	30	20	20	− 15	
yville.....	100	835	Driven wells.....	.....	42	100	46	80	− 8 + 36	Weak.
ıtuck.....	707	600	.....do.....	.....	15	50	20	20	(?)	Do.
on.....	25	720	.....do.....	.....	45	.....	45	.....	.....	
and.....	619	740 760	....do.....	130	18	178	50	50	+ 1 + 5	Do.

[a] Variable.

FLOWING WELLS.

WATSON-OTSEGO DISTRICT.

eference has been made to the occurrence of flowing wells on the tern or inner border of the eastern ridge of the Valparaiso ainic system. There are two districts, one lying north and the

[a] Data from Manual of American Waterworks.

other south of a prominent spur of morainic knolls in Watson Township (T. 2 N., R. 12 W.). The northern district is known as the Wayland, from Wayland village, which is situated on it. This was studied by Mr. Bowman and is discussed by him below. The southern district covers about 5 square miles in southern Watson and northern Otsego townships (see fig. 19). The location of wells and owners' names are from notes by Mr. Udden.

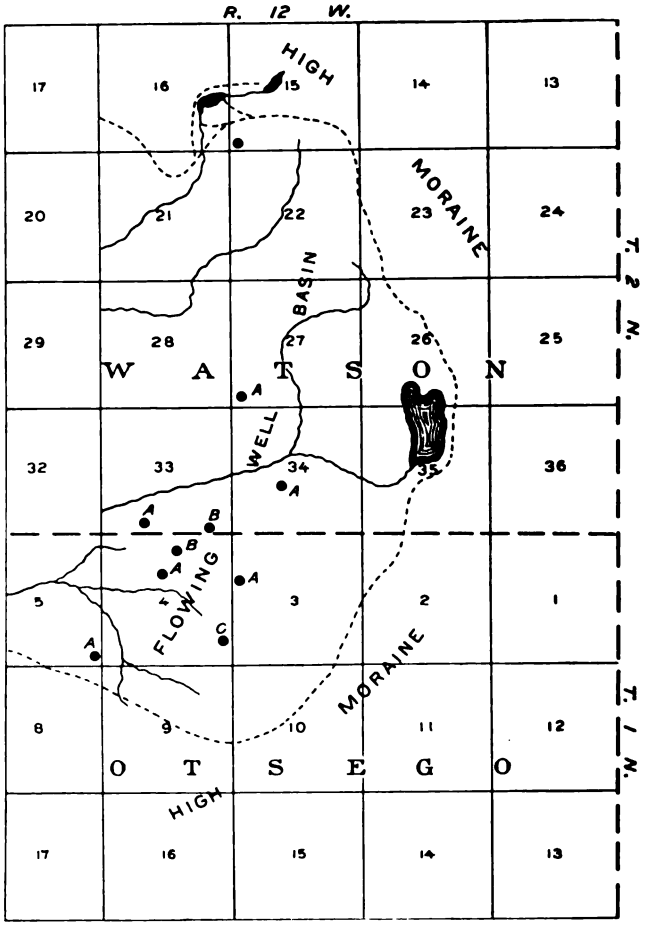


FIG. 19.—Location of flowing wells in Watson and Otsego townships, Allegan County, in relation to topography and drainage

Wells in Watson-Otsego district.

WATSON TOWNSHIP.		OTSEGO TOWNSHIP.	
Grange Hall	Sec. 15	A. McEwer	Sec. 3
Albert Taylor	Sec. 27	Mrs. Charles Edmonds	Sec. 4
Mr. Kitsmüller (2 wells)	Sec. 33	John Krause	Sec. 4
Charles Clock	Sec. 34	Charles Moore	Sec. 4
		Mrs. Helen Dugan	Sec. 5

The following partial analyses are of two nonflowing wells near Watson, the data being furnished by M. O. Leighton of the United States Geological Survey:

Partial analyses of well waters near Watson.

[Parts per million.]

	1.	2.
lor	46	32
on (Fe)	1.5	.5
lorine (Cl)	1.5	1.5
rbon dioxide (CO_2)	134.55	111.68
lphur trioxide (SO_3)	5	5
ardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. F. H. Tefft; depth, 68 feet. 2. John L. Hughes; depth, 92 feet.

WESTERN PART OF COUNTY.

Mr. Udden reports that there are scattered flowing wells southwest f Allegan in Cheshire Township, but he did not secure data on them. It is probable that flowing wells could be obtained along the valley f Kalamazoo River and its main tributary, Rabbit River, for wells on the slopes give a head above the level of the valley bottom, but whether flows have yet been obtained was not learned.

GRAATSCHAP AREA.[a]

One mile west of the village of Graatschap, in sec. 2, T. 4 N., R. 16 W., is a single flowing well on the property of H. M. Lemmer. It is on the western slope of a moraine at an altitude about 65 feet above Lake Michigan. The flow occurs near the tiny valley of a short unnamed stream tributary to Lake Michigan. The head is only a few inches above the surface and the flow 1 pint a minute. The well was drilled in 1896 and has a depth of 90 feet. In a branch of the same valley a mile south of Graatschap the water in tubular wells is within a few inches of the surface, and flows might be secured by trenching. On the east side of this moraine, in an intermorainic basin between Graatschap and Overisel, the water rises almost to the surface in the wells. The bordering moraines are the probable catchment areas for all these wells.

WAYLAND AREA.[a]

The Wayland flowing-well district, in eastern Allegan County, comprises an area of about 30 square miles and is one of the largest in western Michigan. The flows occur near the headwaters of Rapid River, which is formed by the junction of three smaller streams

[a] By Isaiah Bowman.

draining a triangular intermorainic basin. It is between the
which bounds this basin on the east and the two streams at t
of the triangle that the flows occur. There are no flows wes
streams, the water supply here coming from local pockets at
depths in the moraine. The following table is arranged rou

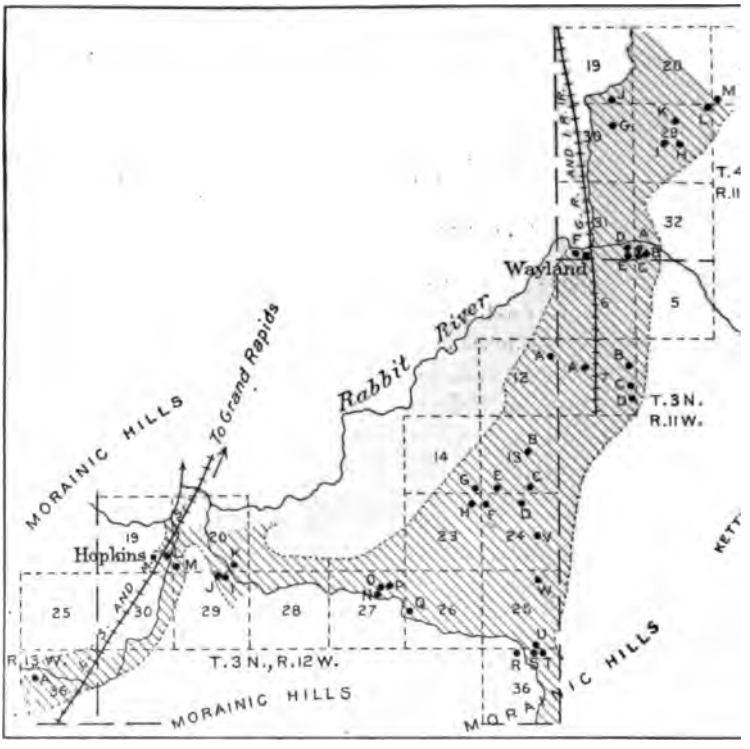


FIG. 20.—Map of Wayland flowing-well district, Allegan County.

three series following the occurrence of the wells from the
each of the converging streams down the valley to their con
The decrease of head in this direction locates the catchment
the moraine lying east of the wells:

Wells at Wayland.

Section.	Letter on fig. 20.	Owner.	Driller.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*
36	A	A. Lohrberg	H. Webber	1897	77	737	762	2	51.2
19	L	Wm. Ederle	G. Webber	1884	90	707	706½	⅛	
20	M	D. B. Kidder			100	707	707		
21	M	A. Brogg	C. Ladd	1892	80	768	772	2	50.8
29	L	J. Steeby	W. Griswold	1896	71	768	772	⅛	
21	K	Mr. Tobin				752			52
29	I	M. C. Heyward	L. Morford	1892	50	752	775	25	50.8
29	H	E. Smith	do	1892	80	757	759	⅓	52
30	G	G. B. Chambers	do	1891	173		+1		
32	A	L. A. Walsh	do	1900	33		+4	4	50.6
32	B	J. D. Stockdale (4 wells)	do	1889	48			¼	51.2
31	F	Wayland (grist-mill).	do	1896	178	745	749	5	51.1
7	A	D. Huttleston	L. Shay	1892	108	723	743	⅛	52.2
7	B	D. J. Sigeler	J. L. Smith	1901	131	753	777	4	51.1
7	D	A. R. Johnston			50	759	762	1½	51.7
7	D	A. Damoth	L. Morford	1896	90	755	777	6	51.2
12	A	S. W. Parker	S. W. Parker	1890	277	727	745	12	
13	B	J. Huggard	B. Catt	1889	130	730	730		
13	C	B. Farnham	C. Yaekly	1893	140	726	736	6	50.2
13	E	C. Simpkins	S. Yaekly	1895	86	723	725	¼	53.3
14	G	F. Wilcox				734		⅛	52
24	F	W. M. Buskirk	W. Brown	1884	115	727	729	⅛	
24	D	A. Baker	C. Yaekly	1895	174	736	740	⅛	
24	V	W. G. McClintock	Brown & Brophy.	1883	80	710	720	2	
25	W	do	do	1883	108		710	2	
36	T	Perry	B. Catt	1886	88	711	715	1½	52
36	S	J. Blair	H. Norton	1887	96	716	727	2	50.8
36	R	School district No. 1.	do	1892				1	
26	Q	I. A. Buskirk		1901	127	702	706	¼	52.2
27	P	J. O'Brien				702	708	1½	53.1
27	O	S. Preslay			100	702	708	2½	51.3
27	N	C. A. Overheiser	W. Brown	1883	109	694	697	2	51.2
20	K	P. Baker	A. Webber	1887	65	709	708	½	
29	I	Walter Bulmer	do	1887	65	709	708	½	
29	J	Wm. Bulmer	do	1904	67	709	708	½	

narked and extraordinary characteristic of the Wayland flows occurrence at greatly differing depths in each of a variable suc- n of clay, sand, and gravel layers, and the uniform increase of toward the east of all the flows, whether from slight or great . The direction of increase points to a supply from the ne on the eastern border of the basin.

lls at Wayland are driven at the rather uniform cost of $1 per The diameter of the pipe used in nearly all cases is 2 inches. vater is everywhere chalybeate in character, most strongly so shallower wells between Bradley and Wayland. The devel- nt of the area began about 1883 and has continued up to the nt, so that the limits of the area are pretty closely defined, igh many more flows could be obtained, especially in the western part between the well of A. Lohrberg and Hopkins n. Unsuccessful attempts have been made to obtain artesian near here, but always on the moraines near by and at an de above the head of the known flows.

The inhabitants of Wayland village are supplied from individual wells, those which flow being located on the lower ground on the north side of the village. Not only the health of the inhabitants but also the proper protection of property commends the installation of a village water system to which the flowing-well supply seems admirably adapted.

Some of the Wayland well drillers maintain that the head of the wells is decreasing, following closely a reported lowering of the water level in the adjacent morainal lakes attributed to better drainage of the area than formerly. Specific data show that such decrease may with better reason be referred to the sand-choked condition of many, if not most, of the wells, a condition depending on the lack of screens in so many of the Wayland wells. When sand pumped the original head is nearly if not quite resumed. A number of cases of interference by a second well near the first have been taken to indicate a very limited supply, but the wells in question are so near each other and both have, on account of their location, such a small head (about 2 feet) that the mutual interference is easily noticeable, an effect which is commonly present but not noticed in wells of greater head. Moreover the wells are shallow here and a study of the well depths in the above table shows artesian water down to rock and beyond, so that no doubt need be entertained of the adequacy of a supply for the village, if the supply is drawn from a considerable depth.

Record of Wayland gristmill well (sec. 31, T. 4 N., R. 11 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	15	15
Clay with pockets of sand	115	130
Sandstone	49	178

The flow continued from top of sandstone, but the water was constantly rolled by the clay from above until a depth of 178 feet was reached.

Record of S. W. Parker flowing well (sec. 12, T. 3 N., R. 12 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	4	4
Gray clay	11	15
Coarse water-bearing sand	92	107
Water bearing quartz gravel, with head of water of −4 feet	5	112
Sandstone with water near bottom	130	242

"True hard rock" at 242 feet.

Record of B. Farnham flowing well (sec. 13, T. 3 N., R. 12 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	128	128
Hardpan	12	140

Water-bearing gravel at 140 feet.

Record of C. A. Overheiser flowing well (sec. 27).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	60	60
Quicksand	20	80
Alternate layers of quicksand and clay	20	100
Hardpan	5	105
Water-bearing gravel and sand	4	109

Record of J. Blair flowing well (sec. 36).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	93	93
Gravel	3	96

Record of W. G. McClintock flowing well (sec. 24).

	Thickness.	Total.
	Feet.	*Feet.*
Loam	4	4
Gravel	26	30
Blue clay	75	105
Gravel	2	107
Hardpan	1	108

Water-bearing gravel at 108 feet.

Record of D. T. Sigeler flowing well (sec. 7, T. 3 N., R. 11 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Sand	20	20
Thin alternating layers of sand and clay, sand water bearing in wet seasons only	20	40
Clay layers becoming thinner and harder	87	127
Coarse gravel	4	131

Flow began at 80 feet and continued to last depth given except in clay layers.

The Grand Rapids and Indiana Railway made a test well near its station in Wayland in 1905 which penetrated sand 25 feet, clay 120 feet, sand 10 feet, sandstone 42 feet, making a total depth of 197 feet. After passing through the clay a small flow was obtained in the lower sand, but the pipe was driven firmly down to the rock and a stronger flow obtained after penetrating the rock a short distance. The flow from this well appears to have lowered the head in surrounding wells, but after flowing a short time it lost head until in

July, 1905, the water in it stands 2½ feet below the surface of the ground. The test has therefore proved unsuccessful in obtaining a strong flow, but by going as deep as the Parker well in sec. 12 there is possibility of an increase in the supply, unless the sandstone proves too close textured.

Below are given partial analyses of waters from drift and rock wells at Wayland, the data being furnished by M. O. Leighton, of the United States Geological Survey. The similarity of the two is striking.

Partial analyses of well waters at Wayland.

[Parts per million.]

	1.	2.
Color	24	19
Iron (Fe)	—1	1
Chlorine	1.5	1.5
Carbon dioxide (CO_2)	83.1	80.02
Sulphur trioxide	0	0
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. A. H. Clark (rock); depth, 145 feet. 2. D. Stockdale (drift); depth, 26 feet.

WATER SUPPLIES OF BARRY COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Barry County is situated north of Kalamazoo County and east of Allegan. Its southern part embraces a reentrant angle where the Kalamazoo moraine of the Lake Michigan lobe connects with the contemporary moraine of the Saginaw lobe. An elevated gravel plain stands in this reentrant angle, on which the villages of Prairieville, Delton, Milo, and Hickory Corners are situated. The moraine and also the gravel plains are thickly set with small lakes which occupy depressions 25 to 100 feet or more below the surrounding land. The moraine just referred to passes eastward along the south side of Thornapple River. A later moraine lies north of the river and this connects near the northwest corner of the county with the Valparaiso moraine of the Lake Michigan lobe. There is an extensive gravel plain in the reentrant angle lying south of the point where these moraines connect, which covers parts of Yankee Spring, Rutland, and Thornapple townships.

Wells are often sunk to depths of 100 feet and in some cases 200 feet or more on the moraines, but on the gravel plains water is obtained at about the level of the lakes, or 25 to 50 feet deep. Mr. Bowman has discussed the public water supplies of Hastings and Nashville, which are obtained from flowing wells, and also a flowing-well district at Woodland in the northeastern part of the county (see p. 163).

WATERWORKS.[a]

HASTINGS.

The city water supply at Hastings, the county seat of Barry County, is derived from one bricked dug well 18 feet in diameter and 20 feet deep, and from six 4-inch wells 55 feet deep. Six 4-inch pipes without screens have been driven into the bottom of the open well, increasing the supply. The dug well is just outside the pumping station, which is on a terrace 12 feet above the surface of Thornapple River and 150 feet south of it, at an altitude of 788 feet. The driven wells are 9 feet lower, or but 3 feet above the normal river level, being located on a narrow flood-plain strip on the immediate bank of the stream.

The pumps in the six wells were at first adjusted to take the natural flow at river level which, together with the supply from the dug well, was about 600,000 gallons daily. Later, an increase of supply became necessary and the air-lift system was introduced, which, at a pressure of 26 pounds to the square inch, immediately increased the possible combined maximum daily draft on all the wells to 1,500,000 gallons. To secure still further increase it is proposed to drive, in the spring of 1905, six 8-inch wells in the bottom of the open well in addition to the six 4-inch wells already there. It is suggested that an increase can be more readily obtained with less interference of flow in the present well by sinking wells some distance up or down the river instead of so near the wells already installed. The capacity of the pumps being 1,500,000 gallons daily and the average actual amount pumped about 400,000 gallons daily, the desired increase is rather for greater ease of pumping and corresponding economy in machinery and fuel than for any real necessity. The present system was established in 1887. Water is furnished to over 800 families.

The preceding data were furnished by F. W. Collins, engineer at the pumping station. W. E. Kelly, former superintendent of the water system, is authority for the statements which immediately follow.

The materials penetrated in putting down the driven wells at the pumping station are as follows: Sand and gravel, 43 feet; blue clay without any admixture of sand, 11 feet; and at a depth of 54 feet very coarse water-bearing gravel.

There are no screens in these wells, the water entering through ⅛-inch holes, of which there are about 300, drilled in each pipe. The coarseness of the water-bearing material prevents all clogging and permits the maintenance of the original flow.

The clay layer noted in the section is found from the other well records to be persistent. It is but 4 feet thick two blocks west of the

[a] By Isaiah Bowman.

pumping station, in John Shay's 39-foot well, which flows slightly at the surface. Near it is another well, which also used to flow but which has since been capped and the flow discontinued.

The village of Hastings stands on a terrace higher than that on which the wells and pumping station are located, thus naturally bringing forward the question of contamination through the surface drainage in the path of which the open well at the pumping station lies. The deeper sources of water beneath the clay are likely to be wholesome because of the continuity of the clay layer above the water bed. The dug well does not have this particular kind of protection, but possibly it is as well protected by other means. Into it the deeper water is allowed to flow, and, having a head 5 feet greater than the surface water, really keeps the surface water out except the little that may possibly enter through diffusion.

The quality of the water may be seen from the partial "mineral" analysis made in 1897 by the Viscosity Oil Company, of Chicago.

Analysis of water of Hastings public supply.[a]

	Parts per million.
Silica	2.6
Oxides of iron and aluminum	6.9
Calcium carbonate	124
Magnesium carbonate	89
Alkaline carbonates	554.1
Alkaline chlorides	5.9
Alkaline sulphates	47
Total solids	329

This is a fair boiler water, the percentage of magnesium being a little high.

NASHVILLE.

Nashville is built on a gently sloping terrace on the south side of Thornapple River. The inhabitants are supplied from individual shallow wells 10 to 20 feet deep, yielding hard water, and from a village system drawing from wells in sandstone more than 300 feet deep. The latter are 6-inch wells driven in 1891, the year in which the present water system was established. The water supplied by the municipal system is used for drinking purposes for a short time only during the winter. Its principal use is for lawns, closets, and fire protection. The deep water is artesian, and has a head of 30 feet. It is said to contain a considerable quantity of magnesium and to be less desirable for drinking purposes than the water from shallow wells.

The capacity of the pumps is 750,000 gallons daily, and the actual water pumped daily is about one-twelfth of that amount. The desired head is obtained by means of a stand tower 12 feet in diameter and 80 feet high, with a capacity of 2,200 barrels. The above data were furnished by D. L. Hullinger, engineer.

[a] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

MISCELLANEOUS VILLAGE SUPPLIES.

The following data on village supplies have been obtained by correspondence with the residents of the respective villages:

Village supplies in Barry County.

Town.	Population.	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Assyria	.....	875 920	Open and driven wells	20	2,300	40	40	.....	Small.
Carleton	.....	825	.....do	20	60	40	40	.....	Do.
Cloverdale	±100	907	Wells and lakes	20	80	40	.....	.....	Do.
Cressey	.....	934	Driven wells	40	80	55	55	−40	Do.
Delton	±200	935	.....do	14	40	30	30	−25	Do.
Freeport	±600	850	Open and driven wells	10	80	30	30	−20	Do.
Hastings	3,172	765 810	.....do	30	70	40	40	+5 −40	Do.
Hickory Corners	±100	925	.....do	25	60	40	40	−30	Do.
Irving	.....	743	Wells and river	10	14	12	12	−10	Do.
Maplegrove	.....	875	Open and driven wells	40	60	40	40	−25	Do.
Middleville	829	730	.....do	20	50	35	35	−30	Do.
Morgan	.....	804	Driven wells and lake	17	64	20	.....	−17	Do.
Nashville	1,164	805	Driven wells	15	308	25	25	+0 −10	Medium.
Orangeville	.....	.....	Open and driven wells	40	80	40	40	−35	Small.
Prairieville	.....	1,000	Driven wells	60	150	75	75	−75	Do.
Woodland	319	820 860	Driven wells, some flows.	30	125	100	100	+5 −30	Do.

FLOWING WELLS.[a]

A few flowing wells have been obtained near Woodland station in northeastern Barry County. All of the flowing wells in this locality were developed about twenty or thirty years ago, and data with reference to them are therefore extremely meager. A flow was first obtained on the farm of T. S. Reisinger one-half mile north of Woodland Center, where a 2-inch pipe was driven down 12 feet into the bottom of a spring. It is well established that clay occurs from this depth to 58 feet, where water-bearing gravel was encountered which gives the present flow. The original normal static head was 11 feet above the surface, but has decreased to 4 or 5 feet at the present time. The well is located on the floor of the valley of School Creek, a small tributary of Little Thornapple River.

One-half mile west of the above well is that of B. O. Smith, which was originally just below the level of the upland on the southern edge of the valley. The decrease in head which this well experienced necessitated trenching to the valley in order to maintain a flow. The same method has resulted in what is practically a flow on the farm of W. A. Greizinger, across the road to the east of the Reisinger well. This well was dug to 80 feet, and on the water rising to within a few feet of the top, trenching to the barn, which is located on the valley side, secured a flow. One-fourth mile north of Mr. Smith's well in the south part of sec. 9 and in the same valley as the three preceding wells there

[a] By Isaiah Bowman.

used to be a flowing well, now no longer in use, concerning which data could not be obtained.

All the records of dug wells and driven wells show the persistent occurrence of a clay layer underneath 10 or 15 feet of surface sand, and it is believed that flows could be obtained throughout the few miles of extent of School Creek.

The flows from the wells in this valley are inconstant, being stronger in wet than in dry seasons. The effect of increased precipitation is felt within a few days.

Two miles west of Woodland Center, on the farm of Mr. Homer in the valley of another small tributary of Litte Thornapple River, a well 200 feet deep used to flow about a pint a minute, but the flow has ceased and the well is at present pumped.

The catchment area of the wells in this district includes but a few thousand acres, and in no field is loss of head more clearly due to waste of water. Although the wells have been cleaned repeatedly the original head is not resumed and the supply is steadily falling off. The enforcement of the law limiting the flow of water in artesian wells would conserve the supply to the advantage of present as well as future well owners in the valley.

Wells in Barry County.

Owner.	Depth.	Diameter.	Elevation.	Head.		Temperature.	Quality.	Flow per minute.	
				Present.	Original.			Present.	Original.
	Feet.	*Inches*	*Feet.*	*Feet.*	*Feet.*	*° F.*		*Gallons.*	*Gallons*
J. S. Reisinger	60	2	820	+4	+11	51.5	Iron	1	.
B. O. Smith	55	2	825	+4	+10	(?)	do	2	

WATER SUPPLIES OF EATON AND INGHAM COUNTIES.

By Isaiah Bowman.

GENERAL STATEMENT.[a]

The greater part of these counties, which stand in the third tie from the south, about midway between the eastern and western bor ders of the State, were examined in part by the writer, but the north ern portions were reported upon by Doctor Lane in the discussion o the region around Lansing (pp. 170-175), the city of Lansing being i the northwestern part of Ingham County. Except for a few squar miles in the southeast corner of Ingham County, which are tributar to Huron River, and for the southern edge of Eaton County, which tributary to Kalamazoo River through Battle Creek, Eaton an Ingham counties lie within the drainage of Grand River, much of th former being tributary to Thornapple, and much of the latter to Ced

[a] By Frank Leverett.

r. The drift in these counties is of moderate depth, so that wells arly every township have reached the underlying rock. Water lies are good both in the drift and in the rock.

WATERWORKS.

EATON RAPIDS.

.ton Rapids is located on the low ground adjacent to Grand r in the southeastern part of Eaton County. The municipal and pumping station are in the southwestern part of the village the Michigan Central Railroad. The supply is derived from -inch wells 60 to 75 feet deep. The normal static head of water 18 inches, the drafted head −10 to −25 feet. Elmer Strope, of ›n, Mich., who has drilled many wells at Eaton Rapids, gives following generalized record of material penetrated in sinking ı at this place:

Generalized section at Eaton Rapids.

	Thickness.	Total.
	Feet.	*Feet.*
ıd and gravel with no water	28	28
ıite sandstone; water bearing	20	48
ıck shale	50	98
ıdy shale	74	172
ıter-bearing sandstone, colored blue when dry	12	184

'he waterworks wells get water from the upper sandstone (No. 2 he section), but, being on higher ground than the village, go deeper their supply.

.n the village there are several flowing wells with a head of 20 to feet and yielding a strong flow. The shallowest are 30 to 35 feet ›p, but the usual depth is about 175 feet. The deeper water is

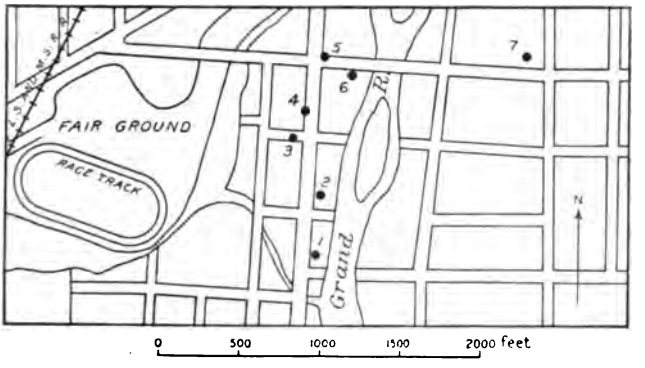


FIG. 21.—Plat of Eaton Rapids, showing distribution of flowing wells.

'h harder than the shallower supply, and the latter is preferred sidents. The principal flowing wells of Eaton Rapids are those) Fred Mendell, (2) George Strunk, (3, 4, and 5) city, (6) Arcana house, and (7) Mrs. U. Arnold. The numbers refer to fig. 21.

An analysis of the public water, made in 1898 by Prof. R. C. Kedzie, of Lansing, gave the following results:

Analysis of public water at Eaton Rapids.[a]

	Parts per million.
Silica (SiO_2)	1.43
Sodium (Na)	11.25
Magnesium (Mg)	18.14
Calcium (Ca)	62.16
Chlorine (Cl)	17.32
Carbonate radicle (CO_3)	134.76
Sulphate radicle (SO_4)	5.04
	250.10
Hardness, by soap test, total	214.29
Temporary hardness	100
Permanent hardness	114.29

The water contains no iron or alumina. It is clear, bright, and destitute of taste and odor.

The capacity of the pumps is 1,500,000 gallons daily, the average amount pumped being 145,000 gallons. The water is forced into a stand tower 14 feet in diameter and 100 feet high; 4¾ miles of distributing mains convey the water to all parts of the village, giving adequate fire protection. The present system was established in 1898 at a total cost of $25,000. About 300 families use the public water, although there are but 250 taps installed.

The present supply is not sufficient during the driest summer months, when the head of water falls off appreciably, indicating that, although in rock, the water is locally supplied. The remedy seems simple, however. More wells installed along Grand River or Spring Brook on considerably lower ground may fairly be expected to meet any demand ever made on them. This position would have the added advantage of allowing suction much below the normal head instead of above it, as is the case at present, during the summer months.

CHARLOTTE.

Charlotte is in the center of Eaton County, 18 miles southwest of Lansing. The pumping station is on the north bank of Battle Creek and about a mile south of the center of the town. The slope of the surface is very gently toward the creek.

The water supply in present use is obtained from five tubular wells 90 feet deep and 6 inches in diameter. The material in which the water occurs is a coarse gravel, which begins about 30 feet below the surface; above it is quicksand and ordinary sand, there being no marked division between the different materials. The water stands at the level of the surface of Battle Creek, and the catchmen

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

ea is probably the bordering gravel plain. The drafted head is uch below the static head, and in consequence the water is practially pumped from the creek into the mains, with this favorable ifference that in the 100 feet between wells and creek the water s drawn through sand, which acts as a natural filter. The dredging ow in progress in the creek will result in lowering the water level nd greater difficulty in securing an adequate municipal supply.

The wells now in use were sunk in 1886 and yielded at that time 1,500,000 gallons daily, but the present daily supply of 400,000 to 450,000 gallons taxes their capacity. To increase the supply and at the same time the ease of pumping, the village is constructing a large open well 20 feet in diameter and 30 feet deep. The curb is built of cement blocks and is being gradually sunk by lowering the foundation. Into the bottom of the well, when completed, will be sunk two 10-inch wells. Great difficulty in lowering the curb has been experienced through the inflow of water and quicksand at a depth of 20 feet. The plant was built in 1886 at a cost of $40,000. Length of mains about 12 miles, supplying all but the outskirts of the city.

An analysis of Charlotte water was made in 1903 at Ann Arbor by Dr. V. C. Vaughan, of the University of Michigan, with the following results:

Analysis of Charlotte public water supply.

	Parts per million.
Total residue after evaporation at 110° C	384
Fixed residue	231.2
Loss on ignition	152.8
Chlorine	8.43
SO_3	0
Free ammonia	.023
Albuminoid ammonia	.032
Nitrates as N_2O_5	Slight trace.
Nitrites as N_2O_3	Slight trace.
Hardness	196.43

No visible development of germs in twenty-four hours. Inoculation negative. Color, clear; odor, none; reaction, alkaline. No evidence that the water can cause disease.

While the analysis shows the water in present use to be pure, the sewer mouth draining the entire filth of the village was heedlessly located but 73 feet downstream from the center of the group of wells, and may very seriously affect the quality of the water. There seems absolutely no good reason why it should not have had its outlet a quarter or even half a mile farther downstream, entirely out of danger distance. With a strong draft at the pumping station, there must be some danger from the sewer, even though the mouth is downstream from the wells, to say nothing of the consequences should an unobserved leak be formed north of the pumping station and in the direct line of drainage toward the wells. This is a condition that should be remedied as quickly as possible.

MASON.

Mason, the county seat of Ingham County, is located about 12 miles south of Lansing. The waterworks pumping station is on the east side of Sycamore Creek, in the northern part of the city. The supply is derived from five flowing wells 150 feet deep and 6 inches in diameter. The flow from the wells is sufficient to keep the pumps supplied with suction. The water flows from a sandstone formation, beginning 40 feet beneath the surface and extending to 200 feet. It appears more porous with increasing depth, yielding a copious flow at 180 feet. During 1903, 37,500,000 gallons were supplied to the city. There are only 323 taps installed, but about 350 families actually use the water. Pressure is secured by means of a stand tower 100 feet high and 16 feet in diameter. The plant was established in 1891 at a cost of $33,650. It is operated in connection with the electric light plant, the whole being superintended by R. E. Darling.

There are several flowing wells in the city owned by private parties. They are along or near Sycamore Creek, or on the lowest ground. Like the public wells they obtain the flow from sandstone.

FLOWING WELLS.

CHARLOTTE DISTRICT.

Four miles west of Charlotte, in sec. 9, T. 2 N., R. 5 W., is a small group of flowing wells on a southern tributary of Thornapple River. They are located very near the head of the tributary known as Bakers Drain, the main drainage line of a flat intermorainic area, bordered on the south by low hills which form the divide between the Grand and Kalamazoo river systems.

The flows are obtained in gravel at a depth of 25 to 40 feet. Above the gravel is hardpan and clay. The surface material, a sandy soil, is 5 or 6 feet in depth. None of the flows are strong, the head being from several inches to several feet above the surface, which has an altitude of approximately 860 feet. The area has been fairly well developed and can not be extended much farther. The water is moderately hard and contains a small percentage of iron. The following detailed descriptions are given:

A. Owner, Frank Baker; drilled in 1888 by Shaw & Tice diameter, 1¼ inches; depth, 42 feet; head a few inches. The flow was not sufficient to supply the amount of water required and the well is now pumped by a windmill.

B. Owner, Lewis Young; drilled in 1904 by J. B. Mount; diameter 1¼ inches; depth, 23 feet; flow, 3 gallons a minute; temperature 50.3° F.; head, 4 feet. The original head was said to be 7 feet. It is reported that when a small lake, called Lazy Lake, 1 mile west of

the well, was lowered 3 feet, the head of the well fell a corresponding distance.

C. Owner, E. E. Bosler; drilled by J. B. Mount; diameter, 2 inches; depth, 23 feet; head, 4 feet; flow, 8 gallons a minute; temperature, 50.8° F.

A flowing well about 30 to 35 feet deep was made in 1897 in the lowland in sec. 5, northeast of Charlotte, on the farm of Eugene Thomas. It struck rock at 30 feet and obtained a sulphurous soft water. Data were furnished by the driller, Elsa Wells, of Charlotte, but the well was not visited. The occurrence of another flowing well in or near the north edge of Charlotte was reported, but not verified.

BISMARCK-ROXANA DISTRICT.

The flows of this area occur in the broad, gently undulating till plain on the divide between Grand and Thornapple rivers in northwestern Eaton County. They are in close association with the drainage, being found only in the low ground adjacent to streams.

In sec. 25, T. 4 N., R. 6 W., is the well of John Childs: Depth, 26 feet; diameter, 2 inches; head, 5 feet; altitude of surface, 930 feet; flow, 10 gallons a minute; temperature 50.2° F. This well was drilled in 1879 by James Phillips. The water flows from a sandy layer which is overlain by clay to the surface. The water is strongly chalybeate.

In the village of Bismarck are at least a half dozen wells, drilled many years ago and now no longer flowing on account of clogging of the screens. Two wells, owned by W. R. Brown and Daniel Ferris, are still flowing. In each the depth is 40 feet; head, 2½ feet; flow, one-sixth gallon a minute, and temperature 52.5° F. The flows in all of the wells are said to vary with the seasons.

In sec. 25, Roxana Township, are the flowing wells of Charles and Sylvester Edgel: Depth, 50 feet; diameter, 2 inches; altitude, 970 feet; head, 2½ feet; flow, 12 gallons a minute; temperature, 50.8° F. The water is strongly chalybeate and occurs in the same material as at Bismarck. The area of flow is restricted to a depression of several acres.

LESLIE DISTRICT.

The village of Leslie stands in the valley of Hunton Creek, in Leslie Township (T. 1 N., R. 1 W.), in the southern part of Ingham County, and has a population of about 1,100. There are 20 flowing wells in the village, ranging in depth from 100 to 217 feet, the average depth being about 160 feet. These wells are owned by individuals and furnish nearly all the water used.

The large percentage of sulphureted hydrogen in the flowing water at this place gives the water, after standing some time, an

unpleasant taste, so that few families use the public supply for drinking. The unpleasant quality is still further enhanced through taste imparted by the tar with which the water mains are smeared inside and out. The water is used, however, by about 60 families for lawn sprinkling and toilet purposes. It is extremely hard but is made much softer by boiling.

The necessary fire protection is secured through a public water system which includes 3½ miles of mains. It was established in 1898 at a cost of $16,000. The municipal wells, 2 in number, are 180 feet deep and 6 inches in diameter. H. C. Yerby supplied the following well record:

Record of waterworks well at Leslie.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy soil	8	8
Sand and gravel, water bearing below 10 feet	12	20
Blue clay	15	35
"State rock"	65	100
"Sand rock," very porous and white at bottom of well	80	180

The average daily amount pumped is 1,700 barrels. The necessary head and pressure is obtained by means of a stand tower 14 feet in diameter and 80 feet high, with a tank having a capacity of 2,300 barrels.

The original head of the flows at Leslie was 10 feet above the surface, but at present it is not more than 6 feet. The flow is apparently affected by the seasons, being reported as considerably less in the dry summer months than during the remainder of the year. The flows are also said to be stronger at night than in the daytime. From 5 to 9 p. m. when the pumps are in most steady operation, the flow in adjacent wells is appreciably decreased.

WATER SUPPLIES OF LANSING AND VICINITY.

By A. C. Lane.

GEOLOGY.

Lansing and its vicinity are wholly underlain, at no great depth, by the coal measures, so that wells may readily reach and draw their supply from the sandstones of that horizon. In fact, the two principal streams, Grand River and its large tributary, the Cedar, are rock bottomed a good part of the way, as appears not only in comparing the sections of the drift shown by wells with the depth of the valleys, but in outcrop and excavation. At Grand Ledge the river flows through a sandstone canyon 40 feet deep for a mile or more. At Lansing the bridge abutments and those of Platt's dam are upon bed rock.

Up Grand River near Dimondale, in sec. 25, T. 3 N., R. 3 W., a sandstone quarry was at one time opened. Also up the Cedar, in sec. 28, T. 4 N., R. 1 E., shales of the coal measures are exposed, and at one time coal was taken from the river bed. The first rock struck is generally a water-bearing sandstone. Consequently the majority of the deeper wells enter the sandstone. Others are merely dug down to gravel at ground-water level.

PHYSICAL CHARACTERISTICS.

CHARACTER OF THE DRIFT.

Because of the abundant supply of water from the rock, drillers have paid comparatively little attention to the variations in the drift or kinds of beds of which it is composed. They tend to class it all as "surface" and urge going on into the rock. The prevailing character of the drift is a clay till, but there are two belts that contain considerable sand and gravel. One is a moraine which leads from east to west past Lansing on the north side of the Cedar and Grand rivers, which has more or less gravelly material in it and outwashed from it over the plain to the south. Sometimes the outwash is covered from 2 to 20 feet deep with a veneer of till, suggesting a readvance of the ice.

The second gravelly belt is known as the Mason esker and runs from the Lansing cemetery southward past Holt and Mason. It is due to deposition from drainage of the ice sheet and runs about at a right angle to the morainic ridge. Along its course are springs and superficial supplies of water. There were other similar deposits near Weberville, Williamston, and elsewhere, but they have been largely used for ballast on roads. In places these ridges reach a height of as much as 40 feet. The Mason esker has apparently been overridden at its north end by the readvance of ice that formed the moraine. The gravel buried under the moraine is traceable northward into Clinton County and supplies wells at moderate depth.

DEPTH TO ROCK.

The depth to rock immediately around Lansing generally varies from 60 to 80 feet, according to the surface topography. In the valleys it is less, but on the morainal ridges it is greater. There have also been found one or two pre-Glacial channels in the rock surface where it is lower down. One of these channels may be traced from Alaiedon Township (T. 3 N., R. 1 W.), where on sec. 9 it is over 105 feet to rock, northeastward through sec. 4, where it is 135 feet, and sec. 3, where it is 180 feet, into sec. 34, Meridian Township, where it is 130 feet, and sec. 23, where it is 148 feet. In the border sections rock is found at 60 to 75 feet. Around Pine Lake bed rock is at 65 feet in sec. 11 and 150 feet in sec. 2, and on the north line of the county 174 feet. We can not follow it definitely in Clinton County,

but it apparently bears northeast into Woodhull Township, Shiawassee County, for in secs. 8 and 17 it is 120 to 125 feet to rock.

East of this valley, from a point near Eaton Rapids northeastward through Aurelius, Vevay, Alaiedon, and Wheatfield townships at least to Williamston, there appears to be a buried ridge in the rock surface, which is often struck at considerably less than 40 feet, and along which wells have in places very soft water.

In Victor Township, Clinton County, a well 155 feet to rock on sec. 19, and 145 feet to rock on sec. 9, may indicate another rock valley, a part of the same system.

In Delta Township (T. 4 N., R. 3 W.) there are puzzling irregularities which if not errors suggest rock valleys. In sec. 35 it is said to be 200 feet to rock; in secs. 24 and 25, from 75 feet to over 135 feet; in sec. 26, 75 feet; in sec. 21, 103 feet; in sec. 20, 80 feet; in sec. 15, 30 feet; in sec. 8, 70 feet; in sec. 7, 55 feet; in sec. 6 is a flow at 80 to 90 feet; in sec. 5 it is 130 feet to rock; in sec. 4, 55 feet; in sec. 3, 75 to 80 feet; in sec. 1, 95 feet.

In Oneida Township (T. 4 N., R. 4 W.), in sec. 18, there is a well 100 feet deep in gravel, but most of the wells in the township, especially around Grand Ledge, find rock much sooner.

In Roxana Township (T. 4 N., R. 4 W.), in sec. 11, on the west side, is a well which goes 210 feet to rock, with pervious beds and water at 231 and 251 feet. In sec. 17 it is but 102 feet to rock. In the south part of the township all the reports are of water in gravel at from 25 to 85 feet, with flows in secs. 28 and 32 (see pp. 169).

QUALITY OF WATER.

The water from the drift is usually harder than that from the sandstone. Around Durand, Byron, and to the south salty water is likely to occur, which may be due to salt water coming up through a fissure, or to an extension of the lower Grand Rapids group.

The following analyses show fairly well the chemical character of the various waters which are likely to occur.

Analysis of Piatt well water.[a]

	Parts per million.
Calcium (Ca)	95.43
Magnesium (Mg)	35.32
Carbonate radicle (CO_3)	187.82
Sulphate radicle (SO_4)	38.88
Silica (SiO_2)	22.60
Iron (Fe)	4.90
Sodium (Na)	48.60
Chlorine (Cl)	107.21
	540.76
Inorganicm atter not present. Difference (O, Na_2O, and Fe_2O_3)	29

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

This well is in the coal measures, and the presence of sulphates significant, but the water is peculiar and has a peculiar history. It 62 feet to bed rock and 115 feet deep. Only 125 feet away is the owney House well, which was put down 740 feet in hope of a flow. one was obtained, and the water grew salty, so the well was plugged 72 feet. When the Piatt well pump is not running the Downey ell[a] stands about 22 feet below ground level, but when the Piatt ell is pumped the Downey drops. The first of the year the Piatt ell was not salt, but lately it has become so through increased use. can give 17,000 gallons an hour, and as much as 6,000 pounds has en used. Evidently the Piatt draws from the Downey well below e plug.

Analysis of well at 1316 Washington avenue south.

	Parts per million.
tal solids	565.6
ganic	96
organic	469.6
lorine	37.2
dium chloride	61.5

Prof. R. C. Kedzie, analyst.

WATERWORKS.

Lansing is supplied by wells from 28 to 350 feet deep. Of these here are 27 in an area of only a few hundred feet near the pumping tation, on Michigan avenue, close to the river. Though the neighorhood is all built up, the water appears safe, and no case of typhoid an be traced to it. This is inferred from the fact that immediately djacent to the pumping station there is a well, that of F. N. Rounseille, which penetrates surface gravels, and is not at all affected by he pumping station. Heavy clays without pebbles, of which 15 feet ere recently seen in the Larned street sewer, come beneath it.[b]

The most of the water is said to come in between 150 and 200 feet own; two wells by the city and a number by the Roe Car Company nd the Oldsmobile works in the south part of the city have shown hat there are heavy water-bearing sandstones from 250 feet down to 50 feet and more. These probably reach the Marshall sandstone, and ould naturally contain less lime than those of the overlying subarboniferous limestone.

The temperature at the waterworks and at the Hazel street flowg well remains almost constant at 51° F. throughout the year, which another sign of freedom from direct supplies of surface water or ontamination. Twice, however, in the winter of 1904–5 bad breaks ccurred in the mains that pass under the river and connect the west ide with the east side on which the pumping station is situated. In iew of this fact, and as the electric plant is under the same manageent, it seems worth considering whether it would not be well to

[a] Proc. Am. Assoc. Adv. Sci., 1875.

[b] For analyses of these waters see above; also Lane, A. C., Lower Michigan mineral waters: Water-p. and Irr. Paper No. 31, U. S. Geol. Survey, 1899.

scatter the wells more and have some on the west side pumped by electric pump.[a] The city is growing rapidly and consumes 1,250,000 to 1,500,000 gallons a day, or about 70 gallons to a person. There are 1,500 meters and 4,000 to 5,000 taps.

The income for the year ending in 1904 was $27,606.58; the expenses for construction (including meters) were $12,194.58; and the operating expenses (including pumping station expenses of $6,299.45) were $14,685.52, making the total expenses $26,880.10.

FLOWING WELLS.

FLOWS FROM DRIFT.

The only known flowing well in Lansing that did not penetrate the rock was one said to be about 30 feet deep near the Lansing waterworks, immediately adjacent to the bluffs of Grand River, and this very likely went to bed rock.

FLOWS FROM ROCK.

While flowing wells from the drift seem now to be scarce, flowing wells from bed rock may be obtained along all the principal lines of drainage, with a head which may vary from 5 to 10 feet. This head is lowered somewhat by the waterworks plants of Grand Ledge and Lansing, but not so as to prevent flows. The following list shows some of the flowing wells associated with the Grand-Cedar drainage system:

Grand Ledge: E. H. Mudge, Seven Island Resort, 107 feet deep; Grand Ledge waterworks wells, 100 to 130 feet deep, temperature 51°; Ball's well, eastern edge of Grand Ledge near the river, 500 feet deep, but flow is not from this depth, temperature 50°.

Lansing: Lansing waterworks wells did flow but are pumped now; Hoffman's well, 700 feet deep, used to flow water at 65 feet; Hazel street well, 350 feet deep, water rises to about 10 feet above river, temperature 51° F., with slight variations from time to time; Old mineral well (which has been variously named, "Senator," "Americanus" or "Lansing Magnetic," or "Michigan Congress"), 1,400 feet deep, but plugged at about 700 feet.

Grand River, main valley: Hazel street well, in the valley of the Grand, about 6 feet above the river, temperature 51.3°; Dimondale, Van Osdalls quarry, sec. 25, T. 3 N., R. 3 W., depth 75 feet, flow 36 gallons a minute, temperature 50.5° F.

Cedar River: It is probable that flowing wells could be obtained east from Lansing along Cedar River to past the Agricultural College. There is one well close to the pickle (formerly Potter's) factory, and another on the Turner farm.

[a] This policy is now, 1906, in process of development.

Sycamore Creek: From Lansing up the valley of Sycamore Creek, ıst Mason, occasional flows have been obtained, there being instances sections 21, 26, 33, and 35, Lansing Township, and as far up as ctions 14 and 15 in Vevay Township.

In 1897 the waterworks wells in Mason (five 6-inch wells) had a ad of 2½ feet, but were on ground 10 to 15 feet below the railroad ıck and 42 feet below the standpipe. Their depth averages about 0 feet with a range from 67 to 172 feet. Mr. S. Lincoln's flowing ll at Mason, 400 feet deep, had water carrying iron and sulphu ed hydrogen in noticeable amount. The temperature was 53° F. well 100 feet deep just south of the railroad station at Mason wed a small stream with temperature 51° F. A flowing well at ıynor's Park, 380 feet deep, discharged a large amount of water.

MISCELLANEOUS FLOWS.

The following table gives data of scattered flows:

Miscellaneous wells near Lansing.

Locality.	Depth to rock.	Depth of rock wells.	Depth of drift wells.	Remarks.
	Feet.	*Feet.*	*Feet.*	
ıton Towhship, sec. 31	100	150	.....	One flowing well in southeast quarter.
ıton Township, sec. 21	40	94	.....	One flowing well in northern part.
ılerville	80	113	25-40	Water in rock at 113 feet.
ıcroft	.....	.....	18-32	North of railroad at 18 feet; south of railroad at 22-32 feet; supply good.
bberville	61-77	133	.....	Water at about 133 feet.
rrice	80	105-328	.....	Water at canning factory is at 192 feet. One mile north salt water occurs at 328 feet.
rry	80-125	125-175	15-35	Shallow wells are in gravel.
nnington	80	150-260	12	
ridian	40-75	75	60	Drift waters are from gravel.
lliamston	.....	40-200	.....	Water from shale at 40 to 60 feet; from sandstone at 165-200 feet.
aftsbury	.....	.....	18-40	Well at railroad got water in gravel at 40 feet.
ingsburg	113	160	45-76	Hard water rising to within 7 feet of the surface was found at 76 feet at Laingsburg mill.
ıslett Park	105	178	30	Water in shallow wells is from gravel
emos	65	80-100	.....	
th	85+	.....	30-50 75-85	Two horizons, lowest in coarse gravel.
arey	100	150	75-100	West of Gearey the wells are 150 feet deep.
ılt	30	40-83	.....	Wells flow.
ricultural College	30-70	40-300	.....	Waterworks are about 300 feet.
owbridge station	70	100	.....	
st Holt	.....	.....	.....	Flowing well near Grand River in rock.
nsing	75	204	.....	Flowing well at Holmes Gardens 1 mile south of city limits.
Do	80-90	209	.....	Flowing well 2 miles south and 1 mile east of Lansing.
nsing Township, section 33.	50	200	.....	Flowing well.
mondale	45-80	.....	.....	Good water at 100 to 200 feet.
lta	50-90	106-140	.....	Good water at 106 to 140 feet in sandstone. Drift has 30 to 40 feet of cemented gravel.
letts	200	.....	.....	Well is at sawmill, probably over the buried channel traceable 5 miles southward.
lta Township, northwest part.	.....	.....	80-90	Flowing well in southeast quarter section 6; south of preceding it is 80 to 90 feet to water.
ta Township, southwest part.	.....	100-150	.....	In southwest part of township it is 100 to 150 feet to good water.
ana Township, sec.	.....	.....	.....	Flowing wells in southeast quarter.
tana Township, sec.	.....	.....	.....	Wm. Litchfield, Mulliken, Mich., completed a well in January, 1904, which flowed 2 feet above surface.
montville	.....	.....	60	Water good.
field stave mill	.....	.....	.....	Soft water at 100 to 126 feet.
field	.....	.....	.....	Wells 40 to 50 feet deep; gas in south part at 20 to 25 feet, from interglacial (?) beds.
wood	.....	.....	40-60	Wells 1½ miles south 30 feet.

WATER SUPPLIES OF OAKLAND COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Oakland County, of which Pontiac is the county seat, is one of the most elevated counties in the southern end of the State, though its southeastern part is down on the lake plain. There is a range in altitude from 1,300 feet down to 630 feet. A strong interlobate morainic system with associated gravel plains occupies more than half the county, leading from the northeast to the southwest corner. Its average altitude is about 1,000 feet, and its highest points may reach 1,300 feet. Southeast of this interlobate tract are weaker moraines formed by the Huron-Erie ice lobe which trend northeast and southwest, parallel with the interlobate tract. About 120 square miles in the southeast corner falls within the lake plain. This has an altitude of 800 feet at the northwest, but drops to 630 feet at the southeast corner. The northwestern part of the county is occupied by moraines formed by the Saginaw lobe, with their associated gravel plains and lines of border drainage. From the interlobate moraine there is drainage southeastward by Clinton River and its tributaries, southwestward by Rouge and Huron rivers, and northwestward through tributaries of Flint and Shiawassee rivers. In addition to the streams there are a large number of small lakes filling many of the basins in the interlobate tract.

Wells are usually obtained at moderate depths on the gravel plains, for these are generally but 20 to 30 feet above the lakes, which determine the depth to which the ground-water table sinks. Wells on the moraines vary greatly in distance to good water supplies, though on the most gravelly parts, as on the gravel plains, the water table is in harmony with the surface of the neighboring lakes. Where the moraines contain considerable till it is often necessary to reach levels lower than the lakes and streams before striking a good water bed. The lake plain is largely a stiff clay in which wells frequently go to depths of 75 to 150 feet. Moraines on the border of the lake plain contain a large amount of clay, and deep wells are numerous in them.

Flowing wells have been obtained in basins and valleys and recesses in the interlobate moraine in the northwestern part, and on the lake plain in the southeastern part of the county. Those in the northwestern part were examined by Mr. Davis, while those in the northeastern part received the attention both of the writer and of Mr. Udden.

Mr. Davis gave attention to village supplies at Oxford, Holly and Ortonville. Data on other village supplies have been obtained by the writer in the course of mapping the glacial formations Mr. Udden, however, gave attention to flowing wells that supply Rochester and Birmingham waterworks.

drift is so thick in Oakland County that but few wells have ırried to the rock. They are chiefly in the lower parts of the at the northwest and southeast corners. Wells at Holly and l, and on farms near these villages get water in sandstone, is struck at 160 to 200 feet. At the Holly waterworks, how- boring penetrated 265 feet to rock and this was a shale. At : the drift is 320 feet, as shown by a test boring for oil and gas d in Geology of Michigan, vol. 5. At Auburn rock is reached feet and at Royal Oak at 164 feet. A boring on the Cooper ½ miles north of Birmingham struck rock at about 200 feet, casional wells in the lake plain have been carried to rock at of 72 to 150 feet or more. At Orion, in the northern part of ınty, shale was struck at 165 feet, and sandstone yielding ater at 185 feet. The water in the rock is saline in the south- part of the county, but is comparatively fresh in the north- ı part.

supplies of water in the drift are generally abundant and of quality than in the rock, and hence there is no need for driving rock. In the southeastern part of the county is a small tract h the water in the drift is saline, as indicated in the discussion Troy flowing well district (pp. 191–192).

WATERWORKS.

PONTIAC.

iac obtains its public supply from wells about 175 feet in terminating in gravel and having a head about level with the . The plant was built by the city in 1888 and water is d direct to the mains, the length of which is about 25 miles. dinary pressure is 45 pounds and fire pressure 100 pounds or

STATE ASYLUM FOR THE INSANE.[a]

State asylum for the insane, located at Pontiac, has a supply ıdent of the city system. It is obtained from a large exca- vell 59 feet deep, in the bottom of which several wells (6-inch nch) have been bored to depths of 40 to 65 feet. The large netrated:

Record of well at Pontiac asylum.

	Thickness.	Total.
	Feet.	*Feet.*
ow clay	10	10
vith coarse stones	6.5	16.5
clay with yellow seams	4.5	21
clay with layers of fine blue clay, very tough	6	27
r sand	1	28
sand, gravel, and bowlders	4.5	32.5
rust	.5	33
d with bowlders and cobblestones	26	59

[a] Data furnished by Dr. E. A. Christian, medical superintendent.

Water was struck at this depth and the borings continued in water-bearing sand to the bottom. One boring found blue clay under the sand at a depth of 119 feet. The pressure is only sufficient to bring water to the bottom of the large well.

MILFORD.

The public supply at this village is from a system of shallow wells along the bank of Huron River. The plant was installed in 1895 and is operated in connection with an electric plant. The mains are about 5 miles in length, and direct pressure is used, the ordinary pressure being 55 pounds and the fire pressure 125 pounds.

The following is a partial analysis of the public supply at Milford, this being obtained from five connected wells. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Milford.

	Parts per million.
Color	10
Iron (Fe)	Very slight trace.
Chlorine (Cl)	23.5
Carbon dioxide (CO_2)	91.53
Sulphur trioxide (SO_3)	15
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 40 feet.

OXFORD.[a]

Oxford is on a broad gravel plain, running, at this point, approximately north and south between two well-marked morainic ridges. This plain is apparently more closely related to the western ridge, from whose base it slopes gently, than it is to the eastern one. Its surface is relatively smooth, and to the east of the town has in it a shallow depression, on the edge of which, about 15 feet below the level of the town, the wells and pumping station of the public water-works are located.

The water for these works comes from a group of five driven wells 6 inches in diameter, which are about 85 feet deep, being in grave the entire distance. The water rises to within about 8 feet of the sur face, and under ordinary pumping is not materially lowered, bu when the pumps are running under fire pressure, 650 gallons a minute is lowered from 10 to 12 feet below this level, and there remain stationary.

The following partial analysis shows the composition of the publi supply obtained from 5 wells at Oxford. It may be taken as a repre sentative sample of the region immediately around Oxford. Th data were furnished by M. O. Leighton, of the United States Geolog ical Survey.

[a] By Charles A. Davis.

Partial analysis of well water at Oxford.

	Parts per million.
Color	46
Iron (Fe)	2
Chlorine (Cl)	11.6
Carbon dioxide (CO_2)	95.37
Sulphur trioxide (SO_3)	5
Hardness (As $CaCO_3$)	139+

* S. J. Lewis, analyst. Depth, 65 feet.

The sanitary conditions in Oxford are such that they deserve especial notice. The gravel plain upon which the town is located is made up of a coarse gravel without any general admixture or interbedding of clay, and hence is very porous, so that water from the surface penetrates it readily, and passes rapidly through it to the water table or ground-water level, which is reported to be 15 to 25 feet below the surface, the differences in depth being due to variations in the ground surface level. As is usual in towns of the size of Oxford, the majority of people obtain water from private wells in the vicinity of their houses. These wells are from 18 or 20 to 30 feet deep, that is, just into the permanent ground water, from which a good supply is obtained.

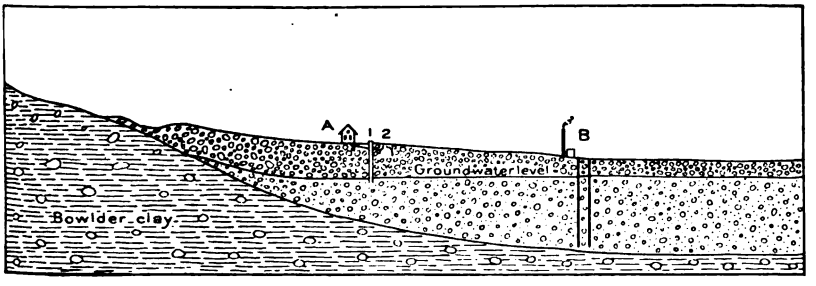


FIG. 22.—Conditions at Oxford, Oakland County. *A*, 1, House well; 2, cesspool open below. *B* Waterworks pumping station; soil above ground-water level is coarse gravel.

Under earlier conditions these wells furnished water free from probability of contamination, but since the comparatively recent installation of the public water service, a constantly increasing number of people have introduced water into their homes for use in bathrooms, etc. Since there is no sewer system to carry off the waste water, the method taken to get rid of this waste is to construct an open-bottomed cesspool near the house, several feet below the surface, wall up the sides and top and run all the sewage into this. The porous gravel of the bottom allows the water to filter out into the soil and find its way where it will (see figs. 22 and 23). The result is manifest; a well-defined short circuit is established from the house to the cesspool, thence to the well, and from the well back to the house again. In this case the only purification which the water gets is filtering through

a few feet of coarse gravel, which in course of time must become badly contaminated by the effete matter which it takes from the water, and by the more deadly, if less disagreeable, germs of disease.

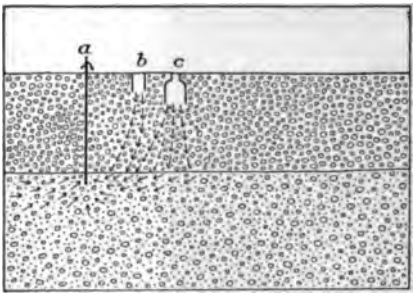


FIG. 23.--Conditions at Oxford, Oakland County. *a*, Well; *b*, privy vault; *c*, cesspool open below.

No sewers have been constructed, because, it is stated, there is no stream in the neighborhood which can be made the terminus of a sewer. However, the proper disposal of this waste is a matter within the grasp of a sanitary engineer, and should be arranged for at an early date. In the meantime, several plans more rational and healthful than that in use suggest themselves, some of which follow:

(1) Dug wells and open wells of all sorts should be abandoned and filled up, as these are especially likely to become contaminated.

(2) If private wells are to be used at all they should be tubular and driven nearly to the bottom of the water gravel, instead of stopping just below the water table. This would insure the most thorough filtration possible, while the latter practice gives the best chances of possible contamination.

(3) Private wells might be abandoned entirely and only the public water supply used. The wells of the waterworks are deep and so far removed from the town that the danger of contamination in them is practically nothing.

(4) All cesspools and vaults should be required by law to be constructed water-tight, and regularly emptied under supervision of a public sanitary inspector, and the contents disposed of in such a way that the health of the community is not endangered thereby.

On the farm of Alfred Hagermann, on the southwest quarter of sec. 23, Oxford Township, within a mile of the town, is a large spring, which is piped to the farm buildings and furnishes a good supply of excellent water. The overflow fills an inch pipe, and the supply is considered "as good as it was twenty years ago."

HOLLY.[a]

Holly is located on a sandy plain traversed by Shiawassee River with higher land near by on the east and south.

The public supply is taken from a group of nine or ten drilled wells 6 inches in diameter, ranging from 23 to 47 feet in depth, all flowing slightly above the surface of the marsh on the edge of which they are located.

[a] By Charles A. Davis.

Below is a partial analysis of the public supply at Holly, furnished by M. O. Leighton, of the United States Geological Survey. The water comes from two connected wells 23 and 85 feet deep, respectively.

Partial analysis of well waters at Holly.

	Parts per million.
Color	42
Iron (Fe)	2.9
Chlorine (Cl)	25.6
Carbon dioxide (CO_2)	121.27
Sulphur trioxide (SO_3)	91
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst.

Owing to the incrustation of the points or strainers of the wells, or to the inflow of sand, several of the wells have become useless and others are failing, so that the supply is inadequate for the needs of the town. In addition to this the ground near the pumping station has become impregnated with fuel oil, stored there at one time, and the water is contaminated by it.

To remedy this state of affairs new wells are being drilled on higher ground, and those completed were reported to be 140, 155, and 180 feet deep, with fair supplies of good water. The water from the 140-foot and 180-foot wells is said to rise in the pipes so that it will flow at the marsh level.

A well over 670 feet deep has also been put down at the waterworks, but the water was slightly brackish and the hole was plugged and the casing drawn back to about 180 feet, where a good supply of water had been shut off in putting down the well. Shale was struck in this well at 265 feet.

The drift materials passed through are as follows:

Section of drift at Holly.

	Feet.
Sand and gravel	140
Clay	10
Water, sand, and gravel	30
Clay	85

The private wells in Holly are generally shallow, varying from 20 to 60 feet in depth, with sufficient supplies for domestic use.

The flowing wells at the waterworks are at the marsh level, below that usually selected for house building, but it seems probable that the borders of the marsh, or any part of it, would give flows. There is no chance of getting flowing wells from these strata on the levels usually occupied by dwelling sites.

Across the valley, opposite the pumping station of the waterworks, and a few feet higher, is a group of seepage springs, not flowing much now, but apparently capable of being cleaned out, and made more efficient.

BIRMINGHAM.[a]

The Birmingham waterworks plant is in the valley of River Rouge, in the western part of the village. It embraces five flowing wells, each 4 inches in diameter, which yield about 40,000 gallons a day. The water discharges into a reservoir, from which it is pumped direct to the mains. The capacity of the reservoir is about 22,000 gallons. The works were put in operation September 1, 1890, and there are at present about 5 miles of mains and 45 hydrants, supplying the principal streets with fire protection and nearly all the residents with water for domestic use. The water, though rather hard, is used to some extent in boilers. There is sufficient iron to give a brown color to the boiler scale.

Field analysis of Birmingham water supply.

	Parts per million.
Hardness	200
Alkalinity	273
Chlorine	38.94

Jon A. Udden, analyst.

ROCHESTER.[a]

The village of Rochester obtains its water supply from flowing wells located on a branch of Paint Creek in the high moraine in the SE. ¼ NE. ¼ sec. 4, Avon Township, Oakland County.

The supply is obtained from five 4-inch wells having an altitude of about 875 and a water level of 888 feet above tide. They range in depth from 60 to 80 feet, and have a flow of about 600,000 gallons a day, or a flow for each well of about 83⅓ gallons a minute. The wells flow directly into a reservoir, which has a capacity of 125,000 gallons, from which the water is distributed to the village, which has an elevation of about 750 feet above tide. The water thus has an average pressure of about 60 pounds throughout the village. The plant was built in 1895, at a cost of $25,000, and at present has about 345 taps, 45 hydrants, and a total of 5½ miles of water main. It is used for domestic, manufacturing, fire, and sprinkling purposes.

The water is harder and more highly mineralized than that of Paint Creek, as shown in the analysis on the next page.

[a] By Jon A. Udden.

Analysis of water at Rochester.[a]

[Parts per million.]

	Village water.	Paint Creek.
ids	369.981	200.010
it red heat	99.995	29.998
esidue	270.843	169.991
(Ca)	77.880	40.040
radicle (CO_3)	114.110	59.960
(Cl)	11.340	7.100
Na)	7.370	4.610
onsumed	7.142	29.998

essed by analyst in hypothetical combinations; recomputed to ionic form at United States al Survey.

Iedzie, analyst, January 12, 1899.

small amount of salt and solids in Paint Creek water renders it or for boiler use to the village supply, and perhaps more suit- or drinking, though in greater danger of pollution.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Oakland County.

n.	Population.	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
iam	1,170	780	Shallow wells in village, deeper flowing wells in valley.	10	90	75	75	−10 +14	Medium.
i	300	1,000	Driven wells			35	35		Small.
		1,025 1,050	Driven or bored wells	20	50	40	40		Do.
g		950 1,025	Driven wells	25	130				Do.
Plains		965	Open and driven wells	14	40	20		−12	Do.
on	530	700 780	Driven and bored wells	15	50	30	30	−20	Do.
		800	Driven wells	15	90	30	25	−10	Do.
		1,000 1,025	do			30	30		Do.
	1,108	920 1,000	do	35	50	50	50		Large.
son		930	do	16	115	50	50	−10	
		900 925	do			30	30	−20	Small.
Lake		937	Lake and driven wells	20	40	20	25	−10	
	1,172	1,060	Driven wells	35	120	60	60 120		Do.
	1,535	750	Driven wells aside from waterworks.	25	277	25			Large.
er		988	Driven wells	15	30	30	26		
k	468	660	do	10	20	20	20		Small.
l		678	Driven well and stream	12	140	40	40		
on	657	940	Driven and bored wells	20	50	25	25		Do.
		1,100	Driven wells	75		75	75	−50	
		745	Open and driven wells.	25	100	40	100	−15	Do.
ake		940	Open and driven wells and lake.	10	117	40	40	−30	Do.
		931	Open and driven wells.	20	50	20	50	−10	Do.
d			do	20	30	25	25		

FLOWING WELLS.

ORTONVILLE DISTRICT.[a]

Ortonville is situated in Brandon Township (T. 5 N., R. 9 E.) in a deep valley, the sandy bottom of which now forms the terraces of a small stream flowing through it. The valley is somewhat less than a mile wide at this point and runs nearly north. Its slopes are generally springy, where the overlying gravelly till rests upon a deposit of much more compact, darker material, which suggests by its character the pre-Wisconsin drift. This springy zone is generally swampy, and there are several interesting springs of considerable capacity running from it and forming roadside rills. (See fig. 24.)

Ortonville is perhaps better supplied with flowing wells than any town of its size in the area visited by the writer, nearly every house having one (see fig. 25). The water seems to come from a single stratum of very fine sand or silt, mixed, in places, with gravel. This

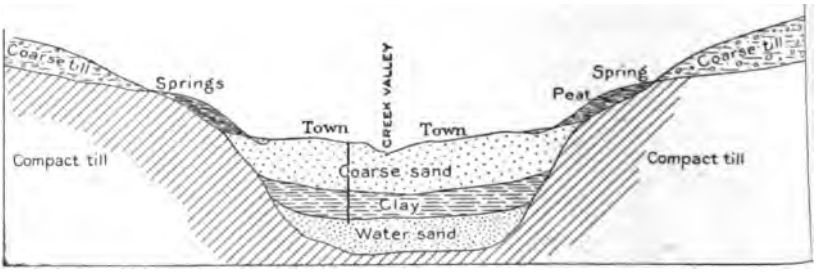


FIG. 24.—Diagram across valley at Ortonville, Oakland County; vertical scale greatly exaggerated

has a cap of from 15 to 30 feet or more of tough blue clay, withou pebbles, on top of which is a layer of sand and gravel from 15 to 3 feet deep. The sandy water bed is about 65 feet below the surfac on the higher part of the district in which flows occur, and is neare the surface in the vicinity of the stream. The first flow was obtaine about 20 years ago, at the mill in the valley. The usual method i to case the wells down into the clay, then bore down to the wate after which the water runs through the clay. The largest flows an strongest heads are found in the stream valley, that of J. H. Man (No. 1 on fig. 25) being located very near the bank of the stream A number of the stronger flows were said to have brought up larg quantities of sand when first put down, that of Milo Giles, at th blacksmith shop, pouring it out by wagon loads for the first thre months after it was put down. Several people also reported tha just before storms their wells flowed more freely, and the wate became roily. This is not unusual in flowing wells, and is due t

[a] By Charles A. Davis.

FIG. 25.—Plat of Ortonville, Oakland County, showing location of flowing wells.

List of owners.

n's slaughterhouse.
n's house.
ts.
varts.
ızo Flagler.
l Bennett.
rad Savener.
ıard Randall.
ı Markham.
ert Hewett.
ıan Patten.
. Bingham.
. Patterson.
j. Brosieus.
Quick.
man Profrock.
s. Profrock.
t. Gulles.
. Addis.
ıle Zimmermann.
. Enders
s. Stevens.
. Patterson.
. parsonage.
. Brosieus.

26. Chester D. Berry.
27. Dr. Gulles.
28. Alex. Stollicar.
29. John Lindsay.
30. Frank Collins.
31. Daver Van Tyne.
32. J. Keller.
33. Lewis Savner.
34. Frank Cliff.
35. Ed Sawner.
36. Louis Givens.
37. Vin. Richmond.
38. George Eaton.
39. Wm. Rathbone.
40. John Skinner (store).
41. Walter Clark.
42. Town well.
43. Frank Frick.
44. William Case.
45. }
46. } Alex. Stollicer.
47. }
48. Nath. Auten.
49. }
50. } Dr. Atcherson.
51. Bert Smith.
52. Hummer & Jones.
53. Alonzo Mills.
54. Schoolhouse.
55. Mrs. Savness.
56. W. J. Ball.
57. James Lane.
58. Mrs. C. S. Rodenbaugh.
59. Daniel Wells.
60. Lovin Torrence.
61. Mill.
62. Mrs. C. S. Stewart.
63. J. J. Evests.
64. R. Skinner.
65. Baptist parsonage.
66. J. J. Evarts.
67. Dr. Uloth.
68. Mrs. Alger.
69. Baptist parsonage.
70. H. R. Jones.
71. Mrs. Mills.
72. G. Terry.
73. N. Welch.
74. L. Purrett.
75. D. Irish.
76. Frick estate.
77. Frank Miller.
78. } Len. Gulles.
79. }
80. Robt. Skinner.
81. Fred. Wilders.
82. A. Sands
83. Thos. Tucker.
84. Milo Giles blacksmith shop.
85. Wm. Petters.
86. Wm. Neally.
87. Mrs. Sands.
88. Westcott.
89. Scott.
90. Geo. Norrin.
91. H. Profrock.
92. H. Frick.
93. Mrs Evarts.
94. Jas. Arnold.
95. Milo Giles.
96. Chas. Kier.
97. Unknown near 29.

lessened atmospheric pressure at such times. The wells at the higher levels of the town are affected by dry weather and some nearly cease flowing in a prolonged drought. This might be in some measure prevented by shutting down some of the large flows in the lowest places, where there is an enormous waste of water, which tends to lower the head of the entire area.

The catchment area might easily be the sides of the valley, especially if the clay capping of the sandy water bed is thin or wanting near the sides, as is possible, or it might be the bottom of the valley itself up the stream, since the head or elevation to which the water rises in the town is only about 15 feet above the stream, and above this level there are no flowing wells.

The following proximate quantitative analysis of the water at the well at Mann's slaughterhouse (No. 1 on fig. 25) shows that the water is not excessively charged with mineral matter, but is of good quality, and while hard is no more so than is usual for waters from the glacial deposits.

Quantitative analysis of well at slaughterhouse (No. 1), Ortonville.[a]

	Parts per million.
Calcium (Ca)	104.51
Carbonate radicle (CO_3)	156.49
Iron (Fe)	2.25
Sulphate radicle (SO_4)	Trace.
Chlorine (Cl)	3.75

It is probable that the entire flow of the area is above 100 gallons a minute or about 150,000 gallons a day, enough for a much larger town. The plat of the village (fig. 25) shows the location of the wells and their relation to the stream, while in the table are to be found statistics of the more interesting wells.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

Representative wells at Ortonville.

·wner.	Diameter.	Depth.	Cost.	Head.	Temperature.	Flow per minute.	Quality.	Remarks.
	Inches.	*Feet.*			°*F.*	*Galls.*		
Marna....	2	35	.....	+20	50.3	8	Hard; iron.	Strongest flow in area.
.....	2	40	.....	+ 6	.....	5	.....do.....	Irrigating lawn.
en Scott..	2	40	.....	+ 2	50.7	8	.....do.....	
Evarts....	.....	65	$15	+ 1	50.2	1	.....do.....	Flow stopped by obstruction.
Enders....	2	50?	.....	+ 3	.....	1	.....do.....	For refrigerating use.
Lindsay ..	2	65	.....	+ 2	51	.....	.....do.....	
n Tyne...	2	50	.....	+ 1	50	.....	.....do.....	Do.
Collins...	2	40	.....	+ 2	51.3	1	.....do.....	Do.
hmond...	2	53	.....	+ 2	.....	1	.....do.....	Sand and quicksand 30 feet; clay 23 feet.
l district..	2	45	.....	+ 9	51.2	.....	.....do.....	
Torrence.	2	48	.....	.....	.....	.....	.....do.....	In creek valley.
. S. Stew-	2	65	.....	.....	51	1	.....do.....	Flowed about a cartload of sand for 3 months.
.. Giles.....	.....	65	20	+ 4	50.2	1	.....	
inner.....	2	50	15	+ 4	53	1	.....	Piped in house; made in 1889.
lders.....	2	50	15	+ 4	53	1	.....	
iles.....	2	65	.....	+ 3.5	52.1	1	.....	Flowed about a cartload of sand a day for 3 days.

ıe farm of Mrs. Loesch, in sec. 29, Brandon Township, 3 miles f Ortonville, is a flowing well about 50 feet deep, with a head above the surface. It is in a sag near a lake, and was reported a very strong flow. This well was not visited by the writer, s reported by the driller, R. E. Cassidy, who also stated that er rises about to the surface in dug wells to the south of Orton- some farms.

GROVELAND TOWNSHIP.[a]

area consists of a group of three wells, in T. 5 N., R. 8 E., ; miles west from Ortonville, one of which (the Thayer well) the rock.

: is probably no communication between these wells, although ly one of the strata passed through in the well of Mr. Thayer same as that which furnished Mr. Coventry's supply. The James Algoe's is an especially fine one, and gives a great y of pure water.

:atchment area is probably in the higher land in the vicinity wells, and it seems likely that wells put down in other low n the neighborhood would also yield flows.

[a] By Charles A. Davis.

Wells of Groveland Township (T. 5 N., R. 8 E.), Oakland County.

Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
			Inches.	*Feet.*	*Feet.*	*Galls.*	*° F.*		*Feet.*	
4	F. W. Thayer [a]	1899	2	175	+2.5	2.5	50.5	Medium hard.	169	Shelly sandstone.
3	J. J. Coventry	1899	2	60 56	+3.25	.....	51.5	Hard	170	Gravel.
5	James Algoe [b]	1899	3	106	+10	4	50.5	do	.....	Gravel and sand.

[a] Water at 40 and 60 feet; nearly flowed at 80 feet; flows from 120 feet.
[b] Said to flow 550 barrels per day. The flow is divided and is piped across the road to the house, where it runs ½-inch pipe full. The well is 8 to 10 feet above the bed of the stream.

BIG MEADOWS AREA.[a]

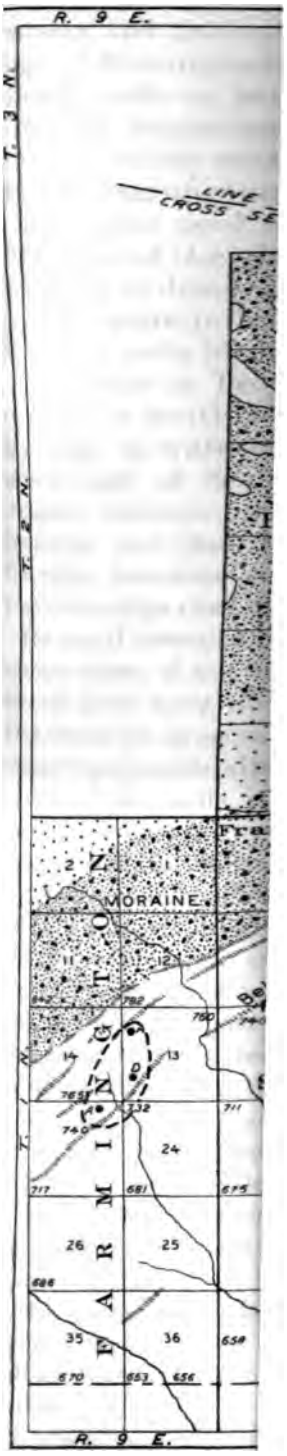
Five miles west of Oxford, in the bottom of a wide valley running from northwest to southeast, is a large area of marsh land, now in part drained and cleared, used for pasture and in some cases for crops. The surface is nearly level, only slight depressions being observed. This is a flowing well area, but is only slightly developed, and but for its possibilities would need no further mention. If, however, the marsh is more fully drained, as it will be sometime, it is a matter of importance to note that practically over its entire surface at depths from 50 to 70 feet flowing water can be found. It was reported that in a number of places wells had been driven to get water for stock in the pastures, but only two were found by the writer. These were flowing up through the bottoms of watering troughs in such a way that no accurate estimate of the flow could be made, but the quantity was probably from 2 to 4 gallons per minute, with a temperature of 51° F. The flows are said to cease after a time, but usually because the pipes become clogged from above. The water just reaches the surface of the general level. The wells observed were on the south side of sec. 24, Brandon Township, near the road, at an elevation of 1,068 feet. On the north side of the valley and marsh, one well was seen which had a head of about 2 feet and a flow of about 3 gallons per minute, but no other information was obtained regarding it. This area is capable of much greater development.

TROY DISTRICT.[b]

Extent.—One of the largest flowing well districts in the southeastern part of the Southern Peninsula of Michigan is known as the Troy district, from Troy Township in eastern Oakland County, in which many of the wells are located. The district, however, extends eastward slightly beyond the Oakland-Macomb county line into Sterling Township, Macomb County, and has also a southwestward extension across the northwestern part of Royal Oak into Southfield

[a] By Charles A. Davis.
[b] By Frank Leverett and Jon A. Udden.

U. S. GEOLOGICAL SURVEY



MAP OF TROY

vnship, and thence northward into Bloomfield Township, past the age of Birmingham. Around the main district are small groups lowing wells or isolated flows whose relations to the main district not yet determined. Pl. V shows the extent of this flowing well rict and of the smaller districts near it in Troy, Bloomfield, South-l, and Farmington townships, which may in some cases prove to in the same pool or district. The relation of these well districts he shores of the glacial lakes, to moraines, and to other features of ography or drainage are also presented. The Troy district covers ut 20 square miles and as at present developed has not far from flowing wells in operation.

'he portion in Troy and Royal Oak townships is nearly shut off n that in Southfield and Brookfield townships by a low, smooth ; ridge (a waterlaid moraine) running southward through the tern edge of Southfield Township. Flowing wells have been ained, however, on this low ridge in secs. 1 and 12, Southfield vnship, and thus connect the fields on either side of the ridge. ; ridge becomes so prominent farther north in Bloomfield and y townships that flowing wells can not be obtained on it.

'he small districts near the Troy district, as suggested above, may some cases, if not in all, be closely related to it and isolated only ause tests have not been sufficient to establish a closer relation. us the wells in secs. 27, 33, and 34, Avon Township, which have a ilar topographic situation in reference to the moraine west of them that of the wells in Troy Township, may, when borings become re numerous, prove to be a part of the Troy field. The isolated up of wells in the northwestern part of Troy Township is separated m the part of the Troy district to the southeast by a morainic ridge high to permit flows to be obtained, but there is a possible exten-n down the valley of River Rouge to the flowing wells at Birming-m. The group of wells in sec. 34, Bloomfield, are likely to belong h those to the east, but the interval of a mile in which no flows ve been obtained leaves the question open. The flowing wells to southwest in secs. 8 and 18, Southfield, and secs. 13 and 23, Farm-gton, are not only separated by an interval of considerable width m those in the Troy field, but two unsuccessful borings by Mr. bbetts in sec. 18, Bloomfield, were carried into the rock and throw ubt on the extension of flowing wells across the interval between e wells in Farmington and those in western Southfield township. ere may, however, be only a local pinching out of the water bed the place where the Tibbetts tests were made. Complete conti-ity of water beds is hardly to be expected throughout an artesian-ll area drawing from the drift deposits, as is the case in the Troy strict. Water beds with strong hydrostatic pressure are so gener-ly distributed through the middle and lower parts of the drift

deposits of this region that it is, on the whole, a more surprisi ture than the occasional failure to strike supply or a supply with sufficient head t

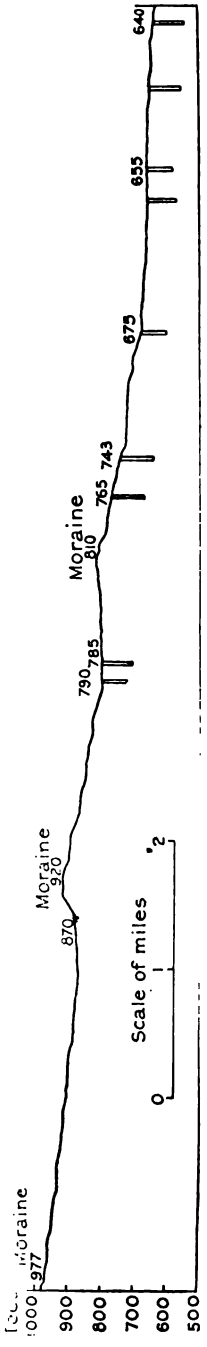


Fig. 26.—Cross section of Troy flowing-well district, Oakland County.

Head.—The cross section (fig. 26) is from west to east across the best develop tion of the Troy field. It takes the direc the most rapid slope, which is about at angle with the trend of the moraines. It to show how rapidly the head falls in southeastward, there being a decrease 100 feet in the 3½ miles from Troy to the border of the district, or nearly 30 feet mile.

There are only a few wells in which th is more than 20 feet, and it probably a less than 10 feet throughout the district head given in the table is, in most cases, the height above the surface at which w escaping from the pipe, for means were hand for testing the full head at the ti other observations were made.

The catchment area for the wells is li embrace a wide extent of high country northwest and not merely the nearest m ridge. The ridge which lies east of River may, however, have a water table high to produce greater head in the flowin east of it than they would have if this rid absent and a plain extended from the wells to the ridge west of River Rouge high altitude of the water table in this ridge may also give the wells south of Bi ham head enough to flow, for it will be ob that the wells there have somewhat great than the wells both to the west and east portion of the ridge south from Birmingh pears to have been formed between the E Huron ice lobes (the Erie lobe on its we the Huron on its east side). The ridge may fore, contain beds which dip to the west as to the east, and distribute the water w collects in both directions. The under water would, perhaps, run westward fro far as the surface water does, or to the ve River Rouge. West from that stream the ground drainage, like the surface drainage, is probably southeas

Structure of drift.—The well owners and the drillers state that the drift is composed very largely of blue clay, which is ordinarily soft or easily penetrated by the drill to a depth of 75 to 130 feet or more. At the base of this clay is a thin crust, usually only 1 to 2 feet thick, overlying the water bed and probably due in some way to the action of the water. The character of the water bed is set forth in the tables below. In most cases wells only reach the top of the bed and do not determine its thickness.

Development.—The Troy field will admit of many more wells without serious interference, if properly distributed and controlled. There are, however, a few cases of the lowering of head and decrease in flow of wells as a result of putting in additional wells. The well of Mrs. Ellinwood, in sec. 20, Troy Township, is thought to have thus affected six other wells in secs. 28 and 29, for their flow seems to be weaker when this well is flowing full strength than when it is shut off. The well of W. Erity, in River Rouge Valley, in sec. 2, Southfield, when allowed to flow to its full capacity, seriously affects the flow of the wells along the bluff of the river in that vicinity and was only checked after suit was brought against the owner. Some wells appear not to have returned to their original strength now that the flow of this well has been lessened. This shows the great need of putting strong wells under control as soon as made.

Aside from the Birmingham public supply, the principal uses made of the flowing wells are the application to the needs of house and stock and dairies. The water holds a temperature of about 50° F. through the summer and serves admirably as a cooler for milk and other dairy products.

Quality.—The principal variation in quality is that of saltness, the eastern portion of the field being characterized by salty water in many of the wells, while the western has in all cases comparatively fresh water. The line at which the change occurs runs about north and south not far from the electric road from Troy to Royal Oak. The saltness of the water in the eastern part of the district seems likely to be due to the escape of salt water into the drift from the underlying rock formations. A well in sec. 23, Troy Township, strikes salty water in sandstone at about 100 feet from the surface. Other wells near by go to greater depths without striking rock, but they may have struck into valleys in the rock filled with sand that receives the salt water from the rock. In one place a salt spring is reported to gush up to the surface, but was not visited, as it is in the midst of a marsh. Mr. Lewis has made analyses of one well in the salt-water and one in the fresh-water area. The amount of the salt in the former (the Lamb well) is more than 10 times as great as in the latter (the Buttolph well), which is considered fresh, though

it has more salt than is usually found in flowing wells from the glacia deposits. The following are the two analyses:

Partial analyses of well waters in Troy district, Oakland County.

[Parts per million.]

	1.	2.
Color	122	96
Iron (Fe)	2	2.5
Chlorine (Cl)	232	2,829
Carbon dioxide (CO_2)	101.97	97.48
Sulphur trioxide (SO_3)	0	10

S. J. Lewis, analyst. 1. J. Buttolph, sec. 22; depth 90 feet; called fresh water. 2. Cyrus Lamb, sec. 23; depth 122 feet; salt water; Udden reports depth 87 feet.

Wells.—The following tabulated data on flowing wells were collected by Mr. Udden; they embrace also wells in isolated districts:

Wells in Troy flowing-well district.

STERLING TOWNSHIP (T. 2 N., R. 12 E.).

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	*In.*	*Ft.*		*Ft.*	*° F.*	*Galls.*	
7	NW.	NE.	Chas. Hawker		640	2.5	95	Gravel	+ 1.5	49	0.75	Hard; salt.
18	NW.	NW.	Eli Renshaw		640	2.5		do	+ 1	49	1.25	Do.
3	NW.	SW.	Utica Village		616		158		+12			
3	NW.	SW.	do		616		(?)		+12			

TROY TOWNSHIP.

1	SE.	NE.	F. Reinholt		±665	2.	89	Gravel	+ 2	48.5	1	Hard; salt.
1	SE.	SW.	J. Dippert		±665	2.	92	do	+ 2	49	1	Do.
4	SE.	SE.	Lakey & Phillips.		±750	2	16	do	+ 2	49	3.5	Hard; iron.
9	NE.	NE.	J. Jennings		750	2.5			+ 2	48	1	Hard.
9	NE.	NW.	Mrs. P. Brandt		765	2.5	98	Gravel	+15	48	4	Do.
10	SW.	SW.	Geo. Dawson		16	2.5		do	+ 2	49	1	Do.
10	SE.	SE.	Geo. A. Clarke		670	2	86	do	+ 4	49	2	Do.
10	NE.	SE.	(?)		680	2.5			+ 3	48.5	1.5	
12	SE.	SE.	A. Jennings		±650	2.5	85	Gravel	+ 2	49	1	Do.
12	SE.	SE.	do		±650	2.5	85	do	+ 2	49	.75	Do.
12	SW.	SW.	Fred Renshaw		660	2.5		do	+ 2	49	1.5	Salt; hard.
12	NW.	NE.	C. Button		665	2.5	95	do	+ 2	49	1	Hard.
13	SE.	NW.	S. C. Hill		650	2.5		do	+ 2	49	1	Salt; hard
13	NW.	NE.	John Harty		650	2.5			+ 2	49	1	Do.
14	NW.	NW.	H. Schneider		670	5	85		+ 2	49	2	Hard; salt
14	SW.	NW.	C. Gratopp	1902	670	2.5	80	Gravel	+15	49	2	Do.
14	SW.	SW.	R. A. Lamb	1897	670	5	85	do	+18	48.5	2	Do.
14	NW.	NE.	W. Schneider	1903	670	2.5	90	do	+15	48.5	2.5	Do.
14	NE.	NE.	J. Renshaw		665	2.5			+15 + 2	49	1	Do.
15	SW.	NW.	J. Aldrich [a]		680	5	130	Gravel	+ 7	49	2	Hard.
15	NW.	SW.	C. Sullivan		690	2.5	135	do	+ 3	49	1	Do.
15	NW.	NW.	F. Belty		706	2.5				49	4	Do.
15	NW.	NE.	do		690	2.5				49	2	Do.
15	NW.	NW.	C. Harris		706	2.5	84		+ 2	49	3	Do.
15	NE.	SE.	J. Measel [b]		670	2.5	85	Gravel	+ 2	49	2	Do.
16	SW.	SW.	J. Dennison		740	5	95	do	+ 2	49	2	Do.
16	SE.	SE.	J. Buttolph	1878	690	2.5	95	Sand	+16	49	7	Do.
16	SE.	SE.	A. Graves		690	2.5			+ 2	49	2	Hard; iron
16	NE.	SE.	J. Scott	1897	705	3	82	Gravel	+ 2	49	12	Do.
16	NW.	NW.	(?)		760							

[a] Blue clay 26 feet, hardpan 2 feet, gravel 2 feet.
[b] Blue clay 75 feet, hardpan 5 feet, gravel 5 feet.

Wells in Troy flowing-well district—Continued.

TROY TOWNSHIP—Continued.

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	*In.*	*Ft.*		*Ft.*	*°F.*	*Galls.*	
17	NE.	SE.	Mr. Lakey		760	2.5						
17	SE.	NE.	S. Butler	1887	760	2.5	110	Gravel	+ 2	49	.5	Hard; iron.
20	SE.	SE.	Schoolhouse	1902	730	4	125	do	+10	49	3	Do.
20	SE.	SW.	Mrs. Ellinwood		740	2.5	112		+ 2	49	1	Do.
20	NE.	SE.	C. Ford		740	2.5	117	Gravel	+ 2	48.5	2	Hard.
21	SW.	NW.	W. Trumbull [a]		725	2.5	112	do	+ 2	49	1.5	Do.
21	NW	SW.	F. Ford		730	2.5	110	do	+ 8	49	1	Hard; iron.
21	NW.	NW.	Adams estate		740	2.5	110	do	+ 2	49	2	Do.
21	NW.	NE.	W. Truesdell	1874	725	2.5	115	do	+ 2	49	2	Do.
21	NE.	SE.	Hill & Becker	1881	690	2.5	130	do	+25	48.5	4	Do.
21	SE.	NE.	S. Donaldson		690	2.5			+ 7	49	2	Hard.
21	SE.	SE.	E. J. Lock [b]	1898	680	2.5	110	Sand	+30	48.5	5	Do.
21	SE.	SW.	E. Dennison [c]		700	2.5	138	Gravel	+10	49	2	Do.
21	SW.	SE.	A. Bailey [d]		710	2.5	138	do	+10	49	2	Do.
22	NW.	NW.	John Buttolph	1893	680	2.5	90	do	+ 3	49	2	Do.
22	NW.	NW.	A. B. Wattles		680	2.5	92	do	+ 2	49	2	Do.
22	NW.	SW.	A. Wegner		680	2.5	130	do	+25	48.5	4	Hard; salt.
22	SW.	SW.	Fred Parks	1900	675	2.5	130	Sand	+10	49	.5	Do.
22	NE.	NE.	J. Schneider		670	2	130	do	+ 2	49	.5	Do.
22	NE.	NW.	Chas. Sturgeon		670	2.5	88	Gravel	+ 3	49	.5	Do.
23	NW.	NW.	Chas. Smith		670	2	80	do	+ 2	49	.75	Do.
23	NW.	NE.	C. Lamb		665	2.5	87	do	+ 2	49	1.5	Do.
23	NE.	NE.	Geo. Lamb [e]	1904	650	2.5	115	do	+ 5	49	.5	Do.
24	NW.	NW.	A. Lamb		650	2.5		do	+ 1	49	1	Do.
26	SW.	SE.	H. Hildebrand		645	2.5		do	+ 2	48	2	Hard; iron.
27	NW.	NE.	A. Gibbs	1889	670	2.5	105	do	+ 2	49	.25	Hard; salt.
28	SW.	NW.	Mr. Herr		700	2.5		do	+ 2	48.5	3	Hard.
28	NW.	SW.	Jas. Phillips		710	2.5	128		+ 2	48	2	Do.
28	NW.	NW.	Miles Dewey [f]	1893	715	2.5	112	Gravel	+ 2	49	3	Do.
28	NE.	NE.	Tom. Boyd		680	2.5	110	do	+15	49	3	Hard; salt.
28	NW.	NE.	M. Spencer		700	2.5	135	do	+ 2	49	1.5	Hard; iron.
29	SW.	SE.	J. Donaldson		740	2.5			+ 2	48.5	2	Do.
29	SE.	SW.	Robt. Groves		725	2.5	115	Gravel	+ 1	49	1	Do.
29	SE.	SE.	A. M. Todd	1900	710	2.5			+ 2	49	2.5	Do.
29	NE.	SE.	Robt. Groves		720	2.5	130	Gravel	+10	48	5	Do.
29	NE.	SE.	do		720	2.5	96	do	+24	48.5	4	Do.
29	NE.	NW.	H. Parks		740	2.5	116		+ 2	49	2	Hard.
29	SW.	NW.	Geo. Dawson		750	2.5			+ 2	49	1	Hard; iron.
30	NE.	SE.	W. Brooks		755	2.5			+ 2	49	1	Do.
31	NE.	NE.	Chas. Moore		750	2.5		Gravel	+ 2	48	2	Do.
32	SW.	NW.	M. Groves [g]	1904	735	4	220	do	+17	49	10	Do.
32	NW.	SW.	P. Lambert	1892	740	3	175	do	+ 2	49	5	Do.
32	NE.	NE.	M. Addison	1886	700	2.5	108	do	+ 2	48.5	3	Do.
35	NE.	NW.	A. Davidson		645	2.5	170	do	+10 + 3	49	2	Salt; hard; iron.
7	NE.	NE.	Ezra Bailey [h]	1890	790	2.5	90	do	+ 3	49	2	Hard; iron.
7	NE.	SE.	J. Dennison		785	2.5	95	do	+ 2	49	2	Do.
8	NW.	NE.	F. D. Cutting	1903	785	2.5	50	do	+ 4	49	3	Do.
33			W. M. Hall		690	2.5	117	do	+(?)			Do.
28			W. Ferkins		690	2.5	115	do	+(?)			Do.
20			J. H. Jackson		(?)	2.5	165	do	− 6			Do.
20			V. James [i]		(?)	2.5	118	do	− 1			Do.
3			Chas. Leonard [j]		710	2.5	116	do	− 9			

[a] Blue clay 107 feet, hardpan 2 feet, gravel 4 feet.
[b] Blue clay 100 feet, quicksand 10 feet.
[c] Blue clay 135 feet, hardpan 2 feet, gravel 3 feet.
[d] Blue clay 130 feet, hardpan 3 feet, gravel 7 feet.
[e] Sandstone 97 to 115 feet.
[f] Blue clay 108 feet, hardpan 1 foot, gravel 3 feet.
[g] Sand 3 feet, pebbly yellow clay 17 feet, pebbly blue clay 97 feet, hardpan 10 feet, cemented gravel 57 feet, clay 30 feet, gravel 6 feet.
[h] Blue clay 85 feet, gravel 5 feet.
[i] Blue clay 116 feet, hardpan 1 foot, gravel 1 foot.
[j] Gravel and clay 13 feet, pebbly blue clay 37 feet, soft blue clay 50 feet, hardpan 7 feet, gravel 1 foot hardpan 7 feet, gravel.

Wells in Troy flowing-well district—Continued.

BLOOMFIELD TOWNSHIP.

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	*In.*	*Ft.*		*Ft.*	°*F.*	*Galls.*	
25	SW.	NE.	Detroit United Railway.	1898	745	2.5	106	Sand....	+ 3	50	2.5	Hard.
25	SW.	SW.	Frank Graglin[a].	.....	738	2.5	40	Gravel..	+ 2	50	2	Do.
25	SW.	SE.	Geo. Shain[b]....	.....	738	2.5	40	....do...	+ 2	50	2	Do.
25	SW.	SW.	Mr. Jacobs[c]....	.....	740	2.5	44	....do...	+ 2	50	2	Do.
36	NW.	NW.	McClellan & Satterlee.[d]	1889	733	2.5	38	....do...	+ 3	51	2	Do.
35	NE.	NE.	J. N. Zimmerman.	1896	733	2.5	38	....do...	+ 2	50	2	Do.
34	NE.	.....	E. T. Brooks[e]..	.....	±760	.....	.....	....do...	+ 3	49	4	Do.
34	NW.	.....	M. M. Fisher[f]..	.....	±770	.....	.....	.....	+ 2	49	1	Do.
36	NW.	NW.	Birmingham waterworks(5 wells).[g]	.....	733	4	45	Gravel..	+14	49	5.20	Do.

ROYAL OAK TOWNSHIP (T. 1 N., R. 11 E.).

6	SW.	NW.	P. Simonoan....	.....	745	2.5	.....	.....	+ 2	49	2	Hard.
6	SW.	SW.	Mr. Roosarde...	.....	730	2.5	187	Gravel..	+ 3	49	2.5	Do.
6	NW.	NE.	S. Cooper.....	.....	745	.....	.....	....do...	+ 2	48	2.5	Do.
6	SW.	NE.	W. Hunt[h].....	1893	740	2.5	165	....do...	+ 6	49	2.5	Do.
6	SW.	NE.	.....do[i].....	1896	740	2.5	126	....do...	+ 2	49	3	Do.
7	NW.	NW.	A. Broadway...	.....	730	.....	.....	.....	.....	.....	.....	

SOUTHFIELD TOWNSHIP (T. 1 N., R. 10 E.).

1	NW.	SE.	John Keyser....	.....	750	2.5	.....	.....	.....	51	4	
1	NW.	SW.	John Nixon.....	.....	750	2.5	100	Gravel..	+ 2	53	5	Hard.
2	NW.	NE.	W. Erity.....	1889	700	6	53	....do...	.....	48	15	Do.
2	SW.	NW.	Erity school-house.	.....	720	2.5	85	....do...	+20	49	4	Do.
2	NW.	SE.	J. Heth[j].....	1895	740	2.5	140	....do...	+11	50	6	Do.
2	NW.	SE.	A. White.....	1904	730	1.5	78	Sand....	+20	48.5	10	Do.
2	NW.	SE.	C. Moore.....	1904	730	2.5	95	....do...	+12	49	10	Do.
2	NE.	SE.	Mrs. McKenney.	.....	730	2.5	97	Gravel..	+ 3	53	3	Do.
2	NE.	SE.	J. Crawford....	.....	745	2.5	.....	....do...	+ 3	49	4	Do.
2	SE.	SW.	Cash Crawford..	.....	745	2.5	114	....do...	+ 4	49	7	Do.
3	NE.	NW.	W. Erity.....	1884	720	2.5	130	....do...	+15	48	3	Do.
	NE.	SW.	.....do.....	.....	720	2.5	85	....do...	+25	48	4	Do.
3	SE.	NE.	W. Master.....	1885	.....	2.5	149	....do...	+22	49	3	Do.
3	SE.	NE.	.....do.....	1887	715	2.5	60	....do...	24	49	12	Do.
11	NW.	NE.	F. Young[k].....	.....	720	2.5	142	....do...	+ 2	49	4	Do.
11	SE.	SW.	C. McDonald...	.....	710	2.5	142	....do...	+ 2	48	3	Do.
12	NW.	SW.	J. D. Evans....	.....	740	2.5	.....	....do...	.....	48	4	Do.
12	NE.	NE.	A. C. Blumberg.	1892	740	2.5	183	....do...	+ 3	48	4	Do.
3	NE.	NW.	J. Bassett.....	.....	715	.....	140	....do...	.....	.....	.....	
18	NE.	NW.	W. Maitrott....	1890	730	2	90	....do...	.....	.....	.....	
8	SE.	SW.	J. Miller[l].....	1894	710	3.5	140	....do...	+20	49	.....	Hard; iron.

FARMINGTON TOWNSHIP.

13	NW.	NW.	A. B. Coleman..	1904	785	.....	.....	Gravel..	.....	53	1	
13	SW.	NW.	.....do.....	.....	740	2	.....	.....	.....	53	1	
23	NE.	NE.	H. Rockwell....	1874	740	2	30	.....	+1	53	.5	

[a] Blue clay 38 feet, gravel 2 feet.
[b] Blue clay 40 feet, gravel 8 feet.
[c] Blue clay 40 feet, gravel 4 feet.
[d] Blue clay 36 feet, gravel 2 feet.
[e] Has 4 other flows.
[f] Has 3 other flows.
[g] Five flows; head+14 feet (or to 747 feet above tide). Yield 750,000 gallons daily.
[h] Blue clay 155 feet, hardpan 4 feet, gravel 6 feet.
[i] Blue clay 115 feet, hardpan 4 feet, gravel 6 feet.
[j] Blue clay 138 feet, gravel 2 feet, a small flow at 113 feet, about ½ gallon.
[k] Clay pretty soft 138 feet, hardpan 4 feet, gravel 18 feet.
[l] Sand and gravel 5 feet, blue clay 40 feet, quicksand 75 feet more or less, hardpan 20 feet, gravel.

AVON TOWNSHIP (T. 3 N., R. 11 E.).[a]

In addition to the waterworks wells (see p. 182) the village of Rochester has two flowing wells, one on the property of the Detroit United Electric Railroad, in the valley of Paint Creek, the other on the property of the Barnes paper mill, near the mouth of Paint Creek, about one-third mile from the railway well.

The railway well was made in 1903 and obtains water from sand at 98 to 100 feet. It has a head of 18 feet and discharges 4 gallons a minute. The water is hard and contains iron. The temperature is 51° F.

The paper mill well was made in 1878 and obtains its supply from gravel at a depth of 150 feet. The water rises to 20 feet above the surface or about 750 feet above tide. It discharges 5 gallons a

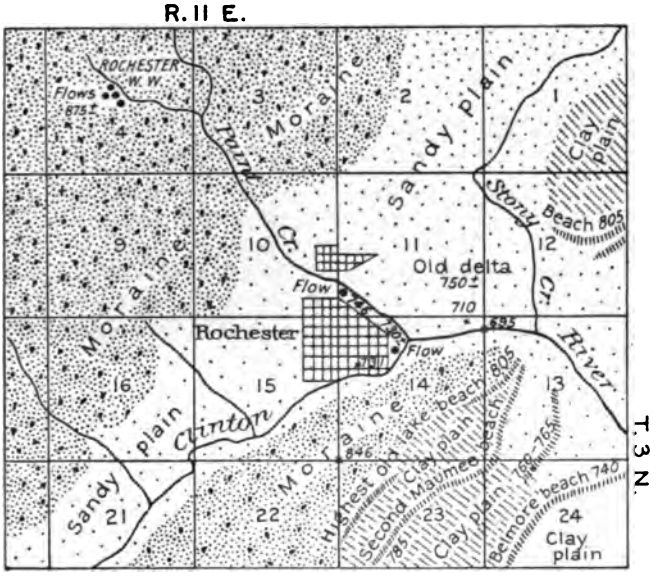


FIG. 27.—Map of Rochester, Oakland County, and vicinity, showing distribution of flowing wells.

minute of hard water, containing some iron. It is probable that the number and area of flows could be extended some distance from Rochester along the valleys of Paint Creek and Clinton River, but the expense of sinking wells to depths of 100 to 150 feet is so much greater than that required to obtain surface water that few attempts have been made to obtain flowing wells.

There are flows in the southern part of Avon Township, in which Rochester is situated, but they are in another district, separated from the wells at Rochester by a prominent morainic ridge and may belong in the Troy field. The wells are tabulated with the other wells of

[a] By Jon A. Udden.

Avon Township, simply for convenience of reference. A boring in sec. 26, which failed to reach rock at 213 feet, also appears in the table, since it shows the great amount of drift present. It also shows that flows are not always obtained when the altitude is similar to neighboring wells that flow.

Wells in Avon Township (T. 3 N., R. 11 E.).

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Feet.	*Ins.*	*Feet.*		*Feet.*	*° F.*	*Gals.*	
4	NW.	SE.	Rochester waterworks.	1895	875	4 4	60 80	Gravel..	+13	.....	.....	Hard; iron.
11	SW.	SW.	Detroit United Electric Railroad, Rochester.	1902	745	6	100	Sand....	+18	51	4	Do.
14	NW.	NE.	Barnes Paper Mill Company, Rochester.	1878	730	4	150	Gravel..	+20	.....	5	Do.
26	NW.	NE.	——(?)[a].....	.....	780	.....	213	.....	.....	.....	.....	No water.
27	NE.	NE.	H. Jungel.....	1896	786	3	150	Gravel..	+ 7	51	5	Hard; iron.
33	SE.	SE.	Mr. Durand[b]...	1878	.....	4	147	....do...	+ 3	.....	.....	Do.
34	SW.	SW.	A. A. Hovey....	.....	.....	2.5	145	....do...	+ 3	.....	.25	Do.

[a] No rock struck or flow obtained.
[b] Blue clay, 90 feet; hard blue clay, 54 feet; gravel, 3 feet.

WATER SUPPLIES OF MACOMB COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Macomb County, of which Mount Clemens is the county seat, fronts on the west shore of Lake St. Clair, and is nearly all tributary to Clinton River, there being only a narrow strip on the shore of Lake St. Clair not tributary to this stream. The entire county has been covered by glacial lake waters except about 50 square miles in the northwest corner where prominent moraines rise above the highest old-lake level. There is a weak moraine, known as the Detroit moraine, running through the lake plain in the eastern part of the county. It governs the course of North Clinton River, which follows its western edge for several miles, and also governs the course of the main river for a short distance before the latter receives its north fork.

The lake plain is not covered extensively with sand, except in the southwestern part of the county. Usually the soil and the material penetrated in wells is a stiff clay, in which are thin beds of gravel and sand, from which wells obtain water. In the sandy tracts water is usually obtained at the base of the sand, at depths of only 10 to 20 feet. The wells in the clay are often but 25 to 30 feet. There are, however, places in nearly every township where water can not be

ınd at less than 50 feet and in some cases 100 feet or even more. ı the morainic tracts in the northwestern part of the county are veral wells more than 100 feet deep, but even there wells generally d water at depths of 25 to 50 feet.

Waterworks have been put in at Mount Clemens, New Baltimore, chmond (including Lenox), Armada, and Romeo. New Baltimore aws its supply from Lake St. Clair, but the other towns depend wells as indicated below.

Flowing wells are obtained on the St. Clair shore along some of the eams and in a part of the lake plain in Armada, Ray, and Washgton townships, which lie east of the high moraines noted above d are probably supplied from these moraines.

But few wells in the county enter rock, and these are nearly all Mount Clemens and south from that city on the border of Lake . Clair. The Mount Clemens wells are several hundred feet in pth and obtain brines used in sanitariums and bath houses, which ıve become so highly patronized as to give the city the name "bath wn." [a]

The following statement concerning the development of the wells as furnished by T. M. Crocker, an attorney at Mount Clemens:

The first well was drilled about 1867 and is now known as the "original well." It was ed for some years as a salt well, but by accident its curative properties were ascertained d a small bath house was erected and used while the waters were still being used for the urpose of manufacturing salt. This well is now used wholly for bathing purposes in a ery large bath house connected with the Avery House and the Egnew. The second well as drilled some time about 1883 or 1884 below the first well, and the water taken in pipes the central part of the city and used in the Medea Bath House, which is connected with he Sherman House. Then there was a third well made, called the Fountain, which is onnected with the Fountain, Clifton, and Crystal hotels by tunnel and covered way. The ourth well was constructed by Keiffer & Buregard, a very fine bath house built, and a ommodious hotel connected with the same. The fifth was constructed by Mr. Coursin, nd the Fenten House is connected with this. The sixth well was made; then the Colo- ial House and Sanitarium were constructed and connected. Each bath house is large and ommodious and the management of each is in all respects first class.

The flowing wells along the shore south of Mount Clemens have only ntered rock in a few cases and have penetrated it a very little disance. The water from near the top of the rock is sufficiently fresh o be used in drinking and is softer than the water from the drift. Salinity increases greatly if wells are continued far into the rock. Wells in other parts of the county that have reached rock find in it vater rather salt for drinking.

WATERWORKS.

MOUNT CLEMENS.

The waterworks plant of Mount Clemens is supplied from a group of 22 wells ranging from 25 to 41 feet in depth, situated in Clinton

[a] For sections of these wells see Geology of Michigan, vol. 5, and for analyses of the water see Water-up. and Irr. Paper No. 31, U. S. Geological Survey, 1899.

River Valley in the southern part of the city. One dug in the summer of 1904 has the following section, reported by the driller, George Rocker: Muck, 2 feet; gravel, 4 feet; sand, 2 feet; blue clay, 4 feet; hardpan, 2 feet; blue clay, 4.5 feet; hardpan, 10 feet; water-bearing gravel, 6.5 feet. It is the bottom gravel that furnishes water to all the wells, some being driven into it farther than others.

The works were established in 1889, and for a time Clinton River water was used, but this proved to be subject to contamination, and a filter bed that was put in is reported by Dr. V. C. Vaughan, of the University of Michigan, to have served as a culture bed for disease germs. The wells have accordingly been substituted. Their location however, on the downstream side of the town seems very unwise. Water is pumped direct to the mains and gives an ordinary pressure of 50 pounds and a fire pressure of 100 pounds.

NEW BALTIMORE.

The public supply at New Baltimore is pumped from Lake St. Clair to a standpipe. Many private wells still in use range in depth from 8 to 24 feet, with a common depth of 20 feet. Rock was struck at 120 feet in a deep boring made some years ago in prospecting for oil.

RICHMOND AND LENOX.

The villages of Richmond and Lenox, which are virtually one community, in northeastern Macomb County, have a public supply from driven wells 130 to 150 feet in depth which obtain water from gravel. The water is pumped to a standpipe. The plant was established in 1895 at a cost of $19,000. The private wells, which are 10 to 25 feet deep, are largely discarded.

In the following partial analyses a comparison is made between the public supply and the shallow well belonging to the proprietor of the hotel at Lenox. The shallow well seems to be heavily contaminated, but fortunately it is used for watering stock only. The data were furnished by M. O. Leighton, of the United States Geological Survey

Partial analyses of well waters at Richmond and Lenox.

[Parts per million.]

	1.	2.
Color	10	107
Iron (Fe)	Trace.	2
Chlorine (Cl)	56.5	76.
Carbon dioxide (CO^5)	82.88	127.4
Sulphur trioxide (SO_3)	10	20
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. City supply; depth, 120 feet. 2. F. Springborn; depth, 10 feet.

ARMADA.

·aterworks supply at Armada is from a flowing well 94 feet ı and 6 inches in diameter, with a head of 16 inches. One ·ein was struck at 15 feet, another at 40 feet, and the third ipal vein at 90 feet. Water is obtained in gravel at each The casing is driven about 40 feet to exclude the upper vein. erworks plant was established in 1903, at a cost of $20,000. nps have a capacity of 750,000 gallons a day and give 42 pressure. The water is soft enough to be used without the of softening compounds.

ɔublic supply has supplanted most of the private wells, ·ere 15 to 25 feet deep, and often obtained water at the base ravel in the Belmore beach upon which the town is built.

·an Atta, of Armada, has a flowing well in a shallow sag, the which will rise 7 feet above the surface. It is a 2-inch well deep and has been running since 1897. The water is soft race of iron. It is cased with tile for 28 feet.

can probably be obtained on the lowest ground in and the village of Armada, but only these two have been reported.

ROMEO.

·aterworks supply of Romeo is from four wells 26 feet deep ine about a mile south of the village. This plant was estab- 1892, at a cost of $36,000. The water is pumped direct to ns and has an ordinary pressure of 60 pounds and fire pres- 100 pounds. Shallow wells are still in use within the city hough they seem an element of danger, the village having experienced an epidemic of typhoid.

ollowing are partial analyses from shallow wells at Romeo, ı being furnished by M. O. Leighton, of the United States ·al Survey:

Partial analyses of well waters at Romeo.

[Parts per million.]

	1.	2.
.....	56	19
.....	2	2
.....	19	21
ıide (CO_2)	90.14	110.36
ɔxide (SO_3)	15	20
ıs $CaCO_3$)	139+	139+

s, analyst. 1. John Kramer; depth, 12.5 feet. 2. City; depth, 15 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

The following data concerning supplies in villages havir waterworks have been largely obtained by correspondence. villages are taken in alphabetical order.

In the vicinity of Center Line, in the southwest part of the co wells are usually dug to a depth of 10 to 16 feet. These wells fail in dry seasons, and some difficulty has been found in g water by driving deeper. Several tubular wells about 100 f depth have been made.

At Disco, in the western part of the county, on a beach line, are obtained at 20 to 30 feet, and there is seldom occasion deeper. The largest supplies are at 30 feet.

At Fraser, in the southern part of the county, wells are gen 12 to 20 feet, but some have been driven to 100 feet. In dry the shallow wells often fail, and water is drawn from Clinton in wagons a distance of 2 miles. The deep wells also are in cases easily exhausted. The best supplies are found at about 9

Near Roseville, in the southern part of the county, there ar low wells 20 feet in depth. Rock is struck at 100 to 150 feet. ordinarily penetrate yellow clay 10 to 25 feet; blue pebbly cl to 50 feet; blue clay like putty with very little grit, 20 to 5 either sand or gravel and water, or a hard clay, that reaches rock. The best supplies are from about 90 feet. As ind below, flowing wells are obtained from this gravel and fro rock in the tract lying between Roseville and the shore of St. Clair.

At Utica wells are commonly about 25 feet with a head of 2 below the surface. Rock is struck at about 200 feet on low g in Clinton River Valley (615 feet above tide) in a deep boring in 1890. Two flowing wells at this village are discussed below

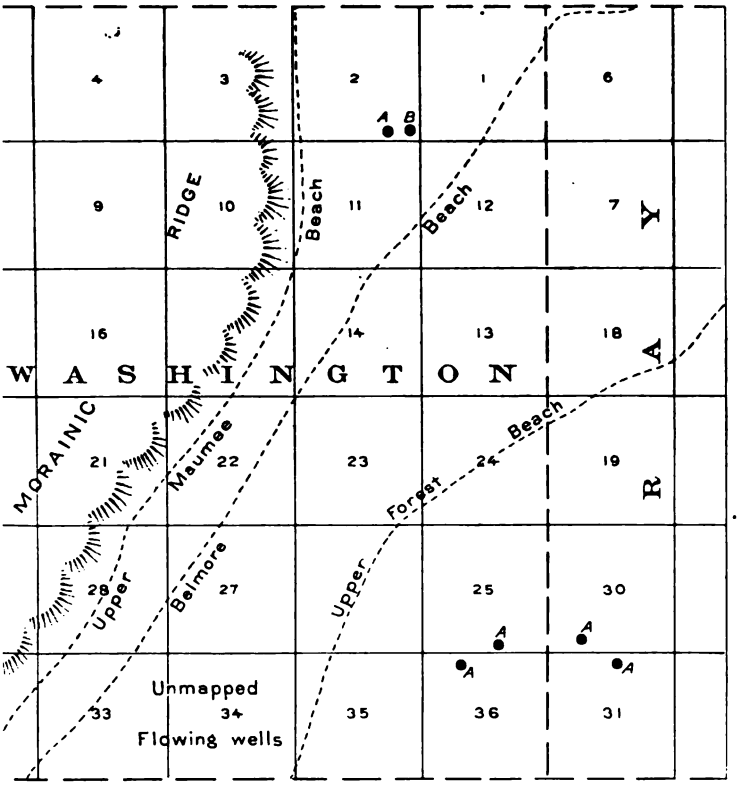
At Waldenburg wells are commonly 50 feet in depth, with 25 feet below the surface. Deeper wells are liable to strike water.

Warren uses shallow wells 12 to 20 feet for the main supply, s mented by cisterns. Water is hard to obtain in the clay

FLOWING WELLS.

BRUCE TOWNSHIP.

ngle flowing well has been obtained on the farm of Frank in the NW. ¼ sec. 22, in the central part of Bruce Township N., R. 12 E.), in the northwestern part of Macomb County. 2-inch well 36 feet deep, has a head of about 10 feet, a flow llons a minute, a temperature of 49° F., and has been running 897.[a] It is situated near the eastern border of a prominent



–Map showing relation of flowing wells in Washington and Ray townships, Macomb County, to lake beaches and moraine.

ne, which, within a mile west, rises to a height of more than et above the well mouth. It is probable that the moraine as a catchment area from which wells along its east border pplied. It is also probable that wells located in sags or low of this border of the moraine will obtain a flow at moderate s.

[a] Data collected by Jon A. Udden.

WASHINGTON-RAY DISTRICT.

The flowing wells of this district were examined by Mr. Udden. The flows are obtained in the lake plain east of the moraine that traverses the central portion of Washington Township in a north-northeast-southsouthwest course (see fig. 28). Two are reported by Udden in the southeastern part of section 2, Washington Township, back of the Belmore beach, at an altitude about 775 feet above tide. The others reported by him are below the forest beach in southeastern Washington and southwestern Ray townships at an altitude about 675 feet. There are, however, flowing wells between the Forest and Belmore beach at an altitude of 700 feet or more that were overlooked by Mr. Udden. Indeed conditions seem favorable for obtaining flows over much of the plain lying between the Belmore and Forest beach if wells are carried to sufficient depth to strike beds whose catchment area is in the elevated country to the west. The flowing wells noted by Mr. Udden in southeastern Washington and southwestern Ray townships are shallow, and perhaps have a near-by catchment area on the plain west of them rather than on the more distant moraine. The water is hard and contains iron in notable amounts.

The wells in Ray Township are from gravel under clay.

The wells in section 2, Washington Township, are from sand under clay, and had a head of 10 feet when struck. The well in section 36 penetrated the following beds: Yellow pebbly clay, 20 feet; blue clay, 18 feet; hardpan, 2 feet; gravel and water at bottom.

Wells in Washington-Ray district (T. 4 N., Rs. 12 and 13 E.).

Letter on fig. 28.	Township.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	°*F.*
A	Washington	2	George Kramer	1900	2	12	775	777	4	50
B	do	2	J. Habor		2		772	774	3	49
A	do	28	Geo. Adams	1888	2	38			6	49
A	do	36	E. Hazelton	1901	2	43			15	48.5
A	Ray	30	W. Wagelin	1894	2	29			2.5	49
A	do	31	W. Gamme		2	20			3	49

UTICA AREA.

The village of Utica, in western Macomb County, is largely built i the valley of Clinton River, and wells are obtained at very moderа depths. Mr. Udden reports that the village has two wells sunk considerable depths, both of which flow and have a head of about feet. The surface is 30 feet below the railroad station and 616 fe above tide. The first well struck the flow in gravel below hard bow der clay at a depth of 152 feet. No accurate data were obtained co cerning the other well, except that it had a similar section and hea

The flowing wells obtained at this village have a head lower than the plain bordering Clinton River at that point. It is unlikely, therefore, that flows can be obtained in this vicinity except along the river valley. There are two flowing wells in the west part of Sterling Township (in which Utica stands) that belong in the Troy flowing-well district, but no flows have been obtained between these wells and Utica. The table for Sterling Township wells is presented with other wells of the Troy field (p. 192).

LAKE ST. CLAIR SHORE.[a]

On the plain bordering Lake St. Clair in Macomb and southern St. Clair County, wells which are sunk nearly to the bottom of the glacial drift and also wells in rock have head sufficient to flow when in the valleys and sags and lowest parts of the plain, but lack a few feet of flowing outside these low places. The majority of the flowing wells are found within 2 or 3 miles of the shore of Lake St. Clair, but in the vicinity of New Haven they are found at a greater distance. They are also found in Clinton River Valley several miles from its mouth in a district back of the Detroit moraine. This latter group should perhaps be considered as separate from those on the plain east of the Detroit moraine.

In southern Macomb County, near Roseville, the flows are found at 50 to 100 feet in gravel beds beneath a stiff clay, and are mainly within 2 miles of Lake St. Clair. The water is soft enough in some cases to use for washing without the addition of softening compounds, and is even preferred to rain water. There is generally sufficient iron present to coat material over which the water flows. A few wells enter the rock at about 100 feet. The water from the rock is likely to be salty, and in some cases can scarcely be used for drinking.

Mr. Charles Barth, of Roseville, who furnished the principal data concerning this part of the St. Clair shore, reports a decrease in head and in volume, attributed to the large draft made by the numerous wells, both flowing and pumped. He also states that flowing wells which have been entirely shut off showed a reduced flow when reopened. Barometric conditions seem also to affect the rate of flow.

Probably the strongest well in this vicinity is that of Bruno Couchez, in the north part of sec. 14, Aaron Township, which is reported to have discharged about 2 barrels a minute when first made, and would shoot a jet into the air from the top of a pipe 10 feet above the surface. The well has a depth of 96 feet. Ordinarily the water rises but 3 or 4 feet above the surface and flows a weak stream. In some cases

[a] The data from the St. Clair district are very meager, although two attempts were made to obtain them. Mr. Udden was instructed to cover this field but stated that he failed to find any flowing wells there. Mr. Cooper afterwards was detailed to collect the data, but seems to have collected data of only a few. He submitted a brief report based upon testimony of persons who chanced to know something of the subject. The present discussion is based partly on the data obtained by Mr. Cooper and partly on information obtained through correspondence.

pumps have been attached to wells that have a head only 1 foot, and as the head becomes lowered many more will have to be supplemented by pumps, for only the strong flows on the lowest ground seem likely to long continue efficient.

Along North Fork of Clinton River are a few flowing wells from drift. One of the most interesting wells is that of Mr. Alfred Little, near Clinton River, about 2 miles northwest of Mount Clemens. The well penetrated 130 feet of clay and there struck a black mucky deposit, apparently an old soil, beneath which was a harder clay than that above. The well was continued to 173 feet, when gas was struck which threw up sand and gravel and a stream of water to a height of 20 feet above the surface. The gas soon escaped, however, and the water dropped to 6 feet below the surface.[a] The flowing-well belt along Clinton River continues northward through the eastern part of Macomb Township, the northernmost well reported being on the farm of A. B. Green in sec. 3.

In Chesterfield Township, which lies east of Macomb, several flowing wells have been obtained 3 to 5 miles from the shore of Lake St. Clair. One on the Joel Hart farm in sec. 7 has been running for 30 years. One on the D. L. Weller farm in sec. 30 is only 22 feet deep. George Fuller has one of similar depth in sec. 19, and wells in that vicinity are generally obtained at less than 30 feet, whether flowing or not.

In New Haven village are shallow flowing wells. One at the residence of Edwin Collins in the north part of the village is 22 feet, and is from a black sandy gravel under a sheet of clay. Mr. Cooper estimates that the area in New Haven in which flowing wells can be obtained is not more than one-sixth of a square mile. There is also reported to be a flowing well one mile south of New Haven. One mile south and 2 miles east of New Haven is a salt spring, and within a short distance from the spring, a flowing well 11 feet deep, with fresh water.

About 3 miles east of New Haven is a group of flowing wells having depths of 80 to 100 feet. They are distributed over a strip about a mile long, northwest to southeast.

In Casco Township, St. Clair County, to the east of New Haven, in places wells are difficult to obtain and borings have been carried to the rock, which is struck at 100 to 200 feet. The water from the rock is brackish, and the farmers have accordingly constructed cisterns and reservoirs which are filled with rain water. Brackish water is said to have been struck at the New Haven depot at 118 feet and 2 miles west of New Haven at 136 feet.

Near the shore of Lake St. Clair, at Fairhaven and north of Anchorville, flows have been obtained. Cephas Rose has a flow at Fair-

[a] Data by W. F. Cooper.

aven. August Kreisel has one north of Anchorville, and there are ther flows about 1½ miles east of Anchorville. The Kreisel well is 25 feet deep and the others 80 to 100 feet.

Several wells near Anchorville have more or less gas with the water. n one case gas was struck at 22 feet, which was burned for sometime nd served the fishermen for a guiding light. One mile west of nchorville gas comes up a short distance offshore and the water here is reported not to freeze in the coldest weather. If confined in barrel it will burn for some time. Mr. Wagner at Fairhaven struck gas sufficient in amount to serve as light and fuel for a year in his welling.

WATER SUPPLIES OF ST. CLAIR COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

St. Clair County, of which Port Huron is the county seat, has its eastern front on Lake Huron and St. Clair River, and its southern front on Lake St. Clair. Its northeastern part is drained by Black River and its main tributary, Mill Creek; its central part by Belle River and Pine River, and its southern end by small streams. The county is largely lake plain, though moraines in the northern part rise above the highest level of the glacial lake which formerly covered the region. There are strips of sand and gravel along the old beaches, but aside from these the surface is generally a stiff clay both on the moraines and plains. The clay is not interbedded with gravel and sand to a sufficient extent to supply wells at all points in the county, and in nearly every township borings have been carried to the rock without striking any water-bearing gravel. On the whole St. Clair is one of the most poorly supplied counties in the State, although the water where obtained in the drift is generally of good quality, and the water from the upper portion of the rock is not generally too salt for drinking. The distance to rock ranges from about 40 feet to 200 feet and more, with a general average of about 125 feet.

There are several small flowing-well districts, one being located in Columbus Township near Hickey, another at Smiths Creek, and another at North street, while scattered flows occur over the southern end of the county and along the valleys in the northern and western parts.

WATERWORKS.

Public water supplies have been installed at Port Huron, St. Clair, Algonac, and Marine City, all of which utilize St. Clair River. The villages of Yale and Capac obtain public supplies from driven wells.

CAPAC.

There is a strip along the eastern base of a morainic ridge running from Capac to Yale, where conditions seem favorable for obtaining flowing wells, but so far as ascertained only one has as yet been obtained, that of Bert Aldrich, in the eastern edge of Capac. This well has been flowing for about fourteen years. It is only 16 feet in depth, and has a diameter of 12 inches. In dry seasons it occasionally stops flowing for a few weeks, so that water has to be dipped from it. In the past three years, however, it has been flowing nearly all the time.

The drift in Capac is from 90 to more than 150 feet in depth, the difference being due largely to the unevenness of the bed rock surface. Indeed, the thickest drift is in the sags, for the drift was not quite sufficient to completely fill the old valleys. The drift in and near Capac is largely a compact blue till, with thin and irregularly distributed deposits of sand or gravel interbedded.

The waterworks wells are n the southwestern part of the village and have been carried a few feet into the rock, which is struck at 90 to 100 feet. The water stands 10 to 15 feet below the surface, but a reservoir or large well has been made into which the wells flow. The supply, both from the drift and the rock, appears to be rather scanty in these wells and also in other deep wells in the village.

Several wells in the village have a decidedly salty taste, among which is one at Hotel De Burt, though in this well rock was not reached. The waterworks wells have a barely detectable salty taste.

The following is a partial analysis of water obtained in the sandstone by the city well at Capac. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Capac.

	Parts per million
Color	19
Iron (Fe)	.7
Chlorine (Cl)	29.3
Carbon dioxide (CO_2)	85.9
Sulphur trioxide (SO_3)	81
Hardness ($CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 100 feet.

YALE.

The village of Yale, in the northern part of St. Clair County, stands partly in the valley of Mill Creek, which here flows between two morainic ridges and partly on the outer slope of the eastern moraine. Flowing wells have been obtained only in the creek valley at a level about 20 feet below the business part of the village, at about 775 feet above tide. The head is barely sufficient to afford flow, being only 3 feet at the waterworks. The flowing wells consi

of a group of five at the waterworks and one private well sunk by Daniel Ferguson. The waterworks wells are 6 inches in diameter, 85 to 90 feet in depth, and were made in 1898. They are all connected by one large pipe with the pumps, and not allowed to flow. About 15,000 gallons a day is the ordinary consumption, and this draft holds the water about 11 feet below the surface. When extra demands are made for lawn sprinkling or in case of fire the head is drawn down to 20 feet or more. The water is from a gravel bed beneath blue clay. Water in the Ferguson well rises to 12 feet above the surface of the ground, about the same height as the waterworks, or 9 feet more than the waterworks wells. Its depth is 445 feet, but the water comes from a fine-grained micaceous sandstone of greenish-blue color, probably Berea sandstone, at a depth of 230 to 245 feet. Below this was a shale formation and no increase of water supply. The temperature is 49.6° F. The drift is 225 feet and the following beds were penetrated:

Record of Ferguson well, Yale.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel	50	50
Blue clay	30	80
Bowlder bed	8	88
Sand and gravelly drift (very little water)	137	225
Blue shale	5	230
Sandstone (Berea grit?)	15	245
Light-colored shale	200	445

A boring at the waterworks, in progress in October, 1904, penetrated a similar amount of drift, and the section differed only in lacking the bowlder bed below the blue clay. The flow of water was struck in the same sand and gravel that supplies the waterworks. In this well the sandstone that supplies the Ferguson well is apparently reduced to a single bed 6 inches thick, in which no water was obtained. A boring in the north part of Yale at a canning factory, on ground 810 feet above tide, or 35 feet above the waterworks, was sunk to a depth of 893 feet, but obtains its main supply from the sand and gravel in the lower part of the drift, the rock being shale as far as penetrated. The water is 22 feet below the surface, practically the same as at the Ferguson well, its level in both being 788 feet above tide. The drift beds are as follows:

Record of well at Yale canning factory.

	Thickness.	Total.
	Feet.	*Feet.*
Clayey drift, rather hard to penetrate	65	65
Bowldery beds	20	85
Sand and gravel with water	140	225

Below are given, for comparison, partial analyses of water from the shallow waterworks well at Yale and from the deep-rock well of D. Ferguson. An analysis was made of this water by Doctor Vaughan at Ann Arbor, which showed it to be dangerously polluted. Mr. S. J. Lewis, who visited the locality and made the present analyses, states that the water is pure and that the contamination reported must have been due to the use of a contaminated vessel in shipping the sample to Ann Arbor. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Yale.

[Parts per million.]

	1.	2.
Color	32	24
Iron (Fe)	.5	1.5
Chlorine (Cl)	121.5	732
Carbon dioxide (CO_2)	83.76	89.3
Sulphur Trioxide (SO_3)	20	69
Hardness (as Ca CO_3)	139+	139+

S. J. Lewis, analyst. 1. City; depth, 70 feet. 2. D. Ferguson; depth, 225 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

City and village supplies in St. Clair County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of well. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Algonac	1,216	590	St. Clair River for public supply; shallow driven wells.	148	5	10	10	10	− 5	None.
Adair		642	Open wells; Belle River.	.....	10	100	30	30	− 8	Do.
Avoca		760	Driven wells	134+	20	134	30	120	−20	Weak.
Berville		815	Open and driven wells.	.....	10	36	20	14	−10	None.
Capac	547	816	Driven wells.	90 150+	16	150	100	90	+ 1 − 7	Weak.
Emmet	265	778	Open and driven wells.	100	15	100	30	.....	−15	None.
Goodells		707	do	.....	12	30	20	20	− 6	Do.
Jeddo		757	do	192+	15	192	50	45	.....	
Kimball		625	Driven wells	136+	18	136	130	100	−18	Small.
Marine City	3,829	590	St. Clair River by waterworks; few wells.	182 230	.....	.....	25	.....	.....	
Marysville		690	St. Clair River; shallow wells.	110	.....	.....	25	.....	.....	
Port Huron	19,158	590 625	St. Clair River by waterworks; few wells.	80 125	.....	.....	.....	.....	.....	
Smiths Creek		624 634	Bored wells	200	40	100	75	75	+ 5 − 10	Do.
St. Clair	2,543	590 630	St. Clair River by waterworks; few wells.	.....	20	150	.....	.....	− 0 − 30	Large.
Wadhams		650	Shallow wells in sand	.....	8	12	.....	.....	.....	None.
Yale	1,125	790 815	Drilled wells by waterworks; open wells.	225	10	900	40	150	+ 4 −20	Small.

FLOWING WELLS.

EAST GREENWOOD DISTRICT.

North of East Greenwood, in the northeast corner of Greenwood ›wnship (T. 8 N., R. 15 E.), St. Clair County, and the southeast rner of Fremont Township, Sanilac County, is a group of shallow ›wing wells. The pool is restricted to a narrow strip, apparently ›t more than one-half mile wide, which runs from the southwest ırt of sec. 36, Fremont Township, in a course south of east to lack River Valley, in sec. 6, Grant Township. The wells are all Fremont and Greenwood townships, but there are springs in the ɔrthwest part of Grant Township which seem to be fed from this ool. The wells either side of this pool go to much greater depths han the flowing wells before finding water, and have a much lower ıead. The flowing wells, as indicated in the table below, are but 12 to 25 feet in depth. They are all hard water and strong in iron, and so are the springs in sec. 6, Grant Township. One well carries a small amount of oil. The wells are on a plain about 80 feet higher than the neighboring part of Black River Valley, or 730 feet above tide. This plain rises gradually westward, reaching an altitude of 770 feet at the border of the Yale moraine, 3 or 4 miles from the wells. The elevation of the crest of the moraine, which is some 3 miles farther west, is 820 to 830 feet. The shallowness of the wells may suggest a catchment area close at hand, or at most no more distant than the Yale moraine; but the fact that the wells and springs are so hard and so strong in iron is thought to be an indication of a somewhat distant source, and may also indicate that the water rises from considerable depths through breaks in the clay. The field is too limited to throw light on the catchment area through the study of the differences in head displayed in passing across the district. Some differences in head are claimed by residents, but the measurements were not taken with sufficient care to warrant any deductions. The wells with lowest temperature in this field are those with most rapid flow. The temperature at bottom is probably about 48° to 49.5° F.

Wells in the East Greenwood district.

Section.	Part of section.	Owner.	Length of time in use.	Depth.	Flow per minute.	Temperature.	Remarks.
			Years.	*Feet.*	*Gallons.*	*° F.*	
36	SE. ¼	D. Nechnier	1	25	0-2	50.5	Water pumped from 14 feet depth. Dug 16 feet; bored 9 feet.
36	SE. ¼	J. Hillock	25	12	1	48.5	Dug and curbed; water escapes into ditch at level of surface.
36	SW. ¼	H. Palmetier	(?)	14	Choked.		Stopped flowing because choked.
36	SE. corner	D. Schell	15+	12	2+	49.5	Flows ½-inch stream.
1	NE. ¼	Joseph Easton	15+	16	2+	51	Dug well, filled with cobblestones.
1	NE. ¼	George Easton	15+	16	1	50.5	
1	N. part	L. Nichols		16	0		Head nearly at surface.

CLYDE TOWNSHIP (T. 7 N., R. 16 E).

North Street station.—There is a narrow strip about 2 miles long near North Street station in T. 7 N., R. 16 E., where shallow flowing wells are obtained, as indicated in fig. 29. The residents along the road that leads north and south past this station, through secs. 1, 12, and 13, found it very difficult to obtain water at their dwellings, and some of them were hauling it from Lake Huron, when by chance it was

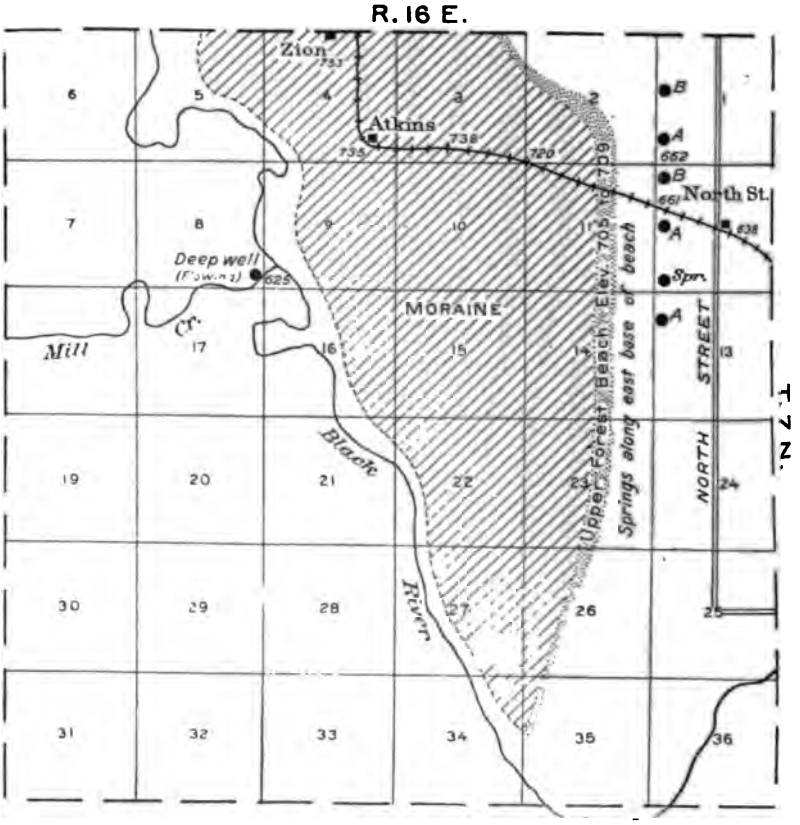


FIG. 29. Map showing relations of flowing wells in Clyde Township, St. Clair County. Shaded a represents part of Port Huron moraine standing above the old lake level.

found that flowing wells could be obtained in the back part of the farms along the western edge of these sections. The ground rises rapid from the road back to these wells, being 635 to 640 feet above ti along the road, and 660 to 665 at the wells. Consequently the he is sufficient to permit piping the water to the dwellings. The depth the wells is only 16 feet, and five have now been obtained. The first, the farm of John Aitkin, in sec. 13, was made about 20 years ago, b the others, on farms of G. W. Davidson, George Lockwood, Charl Lewis, and George Lane, have been made within five years. Th

go through a bed of clay and strike water in sand. The wells are some cases excavated to a depth of several feet to form reservoirs, om which pipes may be carried to the dwellings. The reservoirs over-w into ditches that lead away from the wells. The temperature tober 7, 1904, was 51° F., which is perhaps slightly increased by mospheric heating.

A large sand ridge marking the shore of Lake Warren runs parallel th this line of wells, less than one-half mile distant on the west, but an altitude considerably higher. On the eastern or lakeward bor-r of this sand ridge strong springs are issuing. Immediately west of e ridge and at still higher altitude is the Port Huron moraine. It is obable that the moraine and sand ridge constitute the catchment ea for the flowing wells. The bed of sand from which the flows are tained seems to be a wedge between clay beds or to die out before aching the North Street road. It seems also to be wanting north-ard from the north part of secs. 1 and 2 of this township, for residents rther north have failed to find it or to obtain flows. Further pros-ecting in that region may perhaps give better results. If found at he slight depth at which these flows are obtained considerable pros-ecting might be undertaken for the sake of fully developing the field.

Atkins district.[a]—In the valley of Black River, near the mouth of Mill Creek, about 1¼ miles southwest of Atkins station, a deep boring sunk for oil obtained a strong flow of water from the lower part of the glacial drift at a depth of 116 to 138 feet. The altitude is about 625 feet above tide and the depth 833 feet. The water forced its way up outside the casing, making an opening around the pipe, the strength of the flow warranting belief in the existence of a flowing-well district along that portion of Black River Valley. It may extend up to the East Greenwood district discussed above. The water horizon here, however, is much lower down in the glacial deposits than at the East Greenwood pool.

SMITHS CREEK.

There is a single flowing well at the creamery in the village of Smiths Creek in sec. 31, Kimball Township, about 8 miles southwest of Port Huron. It is in the creek valley about 10 feet below the level of the railroad station, and has insufficient head to flow at the level of the plain bordering the valley. The flow is a gallon a minute, and the water is hard with some iron. It had a temperature of 51° F. at the escape pipe October 13, 1904, but this may be slightly above the temperature of the water bed. The well has been made several years and is about 100 feet deep.

A well at Hotel Fisher, in Smiths Creek village, at the level of the railroad station, is 60 feet deep. The water stands 10 feet below the

[a] Ann. Rept. State Geologist for 1901, p. 278.

surface, and this is said to be representative of the head in t wells in that vicinity. The only territory likely, therefore, t flows is the low land along the creek valley.

COLUMBUS TOWNSHIP.

In the eastern part of Columbus Township (T. 5 N., R. 15 F Clair County, 1 to 3 miles southeast of Hickey Station on the Trunk Railroad, is a group of 11 flowing wells, indicated in f They are found in a tract almost 2 miles long from north to sout about 1 mile wide, embracing parts of secs. 13, 14, 23, 24, 25, a The strongest flow is in the valley of Rattle Run in sec. 14. other wells are on a plain once covered by a glacial lake. The

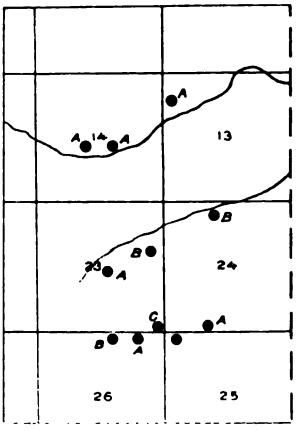


FIG. 30. Flowing wells in Columbus Township, St. Clair County.

an altitude determined by aneroid to 680 feet, while the one lowest valley of Rattle Run is about 66 above tide. The first well was made 30 years ago on the Staley farm in the part of sec. 24. It flowed for many with a strong stream, but now is weak, and apparently is clogged by or by incrustations. The remaind only a few years old, and show but diminution. The water is hard an tains considerable iron. The flow from a bed of sand or sandy gravel a thick sheet of clay. The deepes pass at about 80 feet into an ind clay, which is probably a sheet o older than the surface sheet. The water beds appear to be upon or within this older drift sheet. The temperature of the s est flows is about 50° F., which apparently represents the tempe of the water bed, and agrees with the general averages of wel peratures in this region.

The prospects for extending this area are rather unpromisi several deep wells to the north and east fail to get water witl cient head to flow, though those to the east are on lower ground example, Peter Yeip, in sec. 21, T. 5 N., R. 16 E., has a well 147 fee in which, although the altitude is about 30 feet lower than thes ing wells, the water is 26 feet below the surface. His neighbor Schaffer, in sec. 28, has a well 120 feet deep on ground of simil tude with water 20 feet below the surface. Between there a Clair River the water is seldom nearer the surface than 20 feet

Flowing wells in Columbus Township (T. 5 N., R. 15 E.)

No.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation of well.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
				In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls.*	*° F.*		
	13	Wm. Dupee.....	(?)	(?)	(?)	660	(?)	660	(?)	(?)	Hard...	Water just to surface.
A	14	Otto Kendall.....	1895	2	60	650	590	660	7.5	50	Iron; hard.	Dug 23 feet; bored 37 feet.
B	14	Chas. Silk.....	(?)	2	(?)	660	(?)	660	...	.....	....do...	Head near surface.
A	23	Ezra Whitaker...	1894	2	70	660	595	668	?)	(?)	.....	
B	23	Fred Silk.....	1894	2	70	660	590	665	6	50	Hard...	Water from sand under hardpan.
C	23	Geo. Mackley.....	1898	4	90	660	570	660+	?)	50	....do...	Pump attached; water escapes around pipe.
A	24	Brown farm.....	1904	3	100	660	560	662+	2	49.5	Iron; hard.	Weak flow, 2½ feet head.
B	24	John Staley.....	1875	(?)	60	650	590	660	5	(?)	....do...	Was much stronger at first.
A	45	Chas. Conant.....	?)	4	148	660	511?	665+	3	49.5	....do...	Flows from ½-inch nozzle. Slightly saline.
A	26	S. Chase [a].....	1899	2.5	158	660	532	644	2	50	Hard...	Discharges from 1-inch pipe.
B	26	S. Mackley [b].....	1898	4	116	660	550	660+	.....	50	....do...	Several kinds of material penetrated.

[a] Section of Chase well: Clay rather soft, 80 feet; hard till of brown color, probably pre-Wisconsin, 8 feet; sand, becoming coarser at bottom, 30 feet. The well became clogged and was redrilled in 1901. The original head was but 4 feet and present head is 2 feet.
[b] Water escapes in a ditch and is not carried above the level of the surface.

WATER SUPPLIES OF LAPEER COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Lapeer County, like Oakland on its south border, stands in the reentrant angle between the Saginaw and Huron-Erie ice lobes, and is largely occupied by prominent morainic ridges which traverse the county in a curving course, convex to the north. The southern end of the county has drift knolls which reach an altitude of over 1,200 feet, but with the exception of about 60 square miles in the southern part of the county which stand above 1,000 feet, the elevation is generally between 800 and 1,000 feet. The moraines are separated by valley-like sags, from 1 to 5 miles wide, which were utilized as lines of glacial drainage. The southeastern edge of the county extends slightly into the plain covered by glacial-lake waters, and the northern part of the county is traversed by the Imlay outlet, a line of discharge for Lake Maumee, the earliest of the great Glacial lakes, and now occupied by Flint River. With the exception of a few square miles in the southeastern part drained by Belle River and Clinton River, and an area in the northeastern part drained by Cass River, the drainage of this county is tributary to Flint River.

There is an extensive flowing-well district near Silver Creek in the northern part of the county and smaller ones in or near Lum, Burnside, North Branch, and Columbiaville. There is a belt of flowing wells leading from Hadley southwestward to Ortonville in Oakland County, discussed by Mr. Davis under Genesee County;[a] the other flowing-well districts are discussed below. The flowing wells are distributed in the sags between or among the morainic ridges and may perhaps be developed at numerous other points in the county if care is taken to locate them in depressions near the hills. In some cases it may be necessary to sink them to considerable depths, though those already obtained are usually found at very moderate depth.

At Imlay City, Lapeer, Lum, North Branch, and Columbiaville, and at a few points in the rural districts, wells have been carried to the rock, which at these villages is reached at depths ranging from 50 to 200 feet. The drift is probably 300 to 400 feet thick in the high points in the southern part of the county. The western and northern parts are underlain by the Marshall sandstone, which yields an excellent water, but the southeastern part is underlain by shale, and the water there is somewhat saline, as may be seen by reference to the analyses of the Imlay City water made by Mr. Lewis (p. 215).

WATERWORKS.

Only four towns in the county have public supplies: Almont, Imlay, Lapeer, and Columbiaville.

IMLAY CITY.[b]

Imlay City is situated on the west edge of a broad shallow valley in which flows a small stream half a mile or more east of the town. Within a mile to the north and west are prominent morainic knolls.

The public water supply comes from a group of 5 tubular wells 20 feet apart in a shallow depression just east of the town. Three of the wells are 6 inches and two are 4 inches in diameter. All enter bed rock and range from 155 to 175 feet in depth, with one exception, which was reported to be 300 feet deep. The water is pumped to a standpipe.

The water is somewhat brackish to the taste and is said to be so corrosive that it can not be used with safety in boilers. It is used to some extent at the pumping station. It is also rather hard and deposits scale and is not generally liked and little used because of its "mineral taste," the "mineral" being principally salt. The following analysis shows its character:

[a] See Water-Sup. and Irr. Paper No. 183.

[b] By Charles A. Davis.

Analysis of water from public well, Imlay City.[a]

	Parts per million.
Total solids	1,580.07
Volatile at red heat	120
Mineral matter	1,460.07
Sodium (Na)	508.30
Chlorine (Cl)	781.73
Sulphate radicle (SO_4)	Trace.
Temporary hardness by soap test	100
Nitrates	None.
Nitrites	None.
Free ammonia	25
Albuminoid ammonia	.05

Dr. R. C. Kedzie, analyst. Water is usable.

Following are additional partial analyses from a deep and a shallow well at Imlay City. The water from the deep well is too salt for drinking except by those used to it. That from the shallow well, though showing much less salt, contains a considerable amount, probably due to the escape of saline water from the underlying rocks. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Imlay City.

[Parts per million.]

	1.	2.
Color	10	64
Iron	Strong trace.	1
Chlorine	1,039	251.5
Carbon dioxide	74.77	135.65
Sulphate radicle (SO_4)	159.57	109.81
Hardness	139+	139+

S. J. Lewis, analyst. 1. City; depth, 162 feet. 2. City; depth, 18 feet.

This water is used for fire protection, for sprinkling, and for general purposes by some of the people, but is not as much used as it would be if it were freer from salt.

Record of Imlay City waterworks wells.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	16	16
Sand	37	53
"Salvey" clay	10	63
Clay	14	77
Sand, rock, and clay	7	84
Clay and sand	9	93
Shale	10	103
Soapstone and sandstone to bottom to water	52	155

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The Grand Trunk Railway pumps water from the stream east of the town to supply the water tank at the station, not w to use the saline water of the town supply in the boilers.

The wells of the town are mainly shallow, from 20 to 50 f depth, with sufficient water.

Wells in the country near Imlay City in some cases reach c of over 300 feet deep and are not infrequently 100 feet. Amo deeper are the following:

Wm. Snowden, 2½ miles northwest of Imlay City, in sec. 6, T. R. 12 E., has a well 335 feet deep; made in 1896; 2-inch cased to rock at 200 feet; water level—35 feet; first water feet, small vein; water soft; turns dark colored and then cle at intervals of several days.

John Sisson, in sec. 33, T. 7 N., R. 12 E., has a well 153 feet made in 1901; 2-inch casing for 84 feet; shale at 80 feet; rock at 148 feet; drift mainly sand and gravel; water leve feet.

Milo Quirk, sec. 19, Imlay Township, has a well 187 feet drilled in 1891; 2-inch diameter; water level—24 feet; ro 115 feet.

LAPEER.[a]

The city of Lapeer is situated along the sides of the shallow of Farmers Creek and spreads out over the adjacent rolling co which is largely a clayey till.

The waterworks wells are located near the bank of the stre the lowest terrace of the valley. There are six, put down in all 8 inches in diameter. They are in sandstone and are from 290 feet deep, striking rock at 100 feet from the surface, an with a head of about 4 feet. The amount of water used by t per day was given as between 500,000 and 600,000 gallons, the time the writer visited the plant there was a 2-inch ov from time to time, in spite of the fact that the pumps were w at usual speed. When pumped hard, the water is lowered to below the surface. The supply is ample for the present needs town.

As is usual in a town of this size, there are many private ranging in depth from a few feet to nearly 300 feet. In the the supply is obtained from the sandstone, as in the wells waterworks. The shallow wells are dug or tubular and ra depth from about 20 to 100 feet. No flowing wells were found from those at the waterworks.

MICHIGAN HOME FOR FEEBLE-MINDED.[b]

ıall sandstone. The head is 6 feet below the surface, and the are reported to have a capacity sufficient to supply an institu- ıf 2,000 (or 2½ times the present number) for all purposes. The · contains a small amount of lime and is of excellent quality.

ALMONT.

ɜ village of Almont has a tank to which water is pumped and for fire protection and for sprinkling streets, but is not drawn for domestic use.

COLUMBIAVILLE.

ɜ water supply of Columbiaville is in charge of the manager of eters estate, the plant having been put in by Mr. Peters. Appli- ı was made for information concerning the plant, but was not ed. Flowing wells on the Peters estate and at other points near ıbiaville are discussed below.

MISCELLANEOUS VILLAGE SUPPLIES.

ɜ data below were obtained largely by correspondence with the nts of the respective villages.

Village supplies in Lapeer County.

·n.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
.....	718	831 850	Driven and bored wells; some old dug wells. Waterworks for fire protection and sprinkling.	140	10	165	16	80	−20	Small.
.....	350	900	Open and driven wells.	50 150	10	200	25 37	 37	−20 + 7	Do.
e.....	.....	±800	Flowing wells	109	.....	.....	.....	.....	.....	Do.
.....	339	835	Driven wells.....	60 ? 205	16	205	.....	205	−6 +10	Do.
iaville.	457	760	Driven wells; Flint River by waterworks.	100±	25	100	60	50	−10	Do.
.....	328	920 960	Open and driven wells.	.....	25	100	50	50	−25	Do.
.....	.....	858 875	Driven wells.....	100±	45	115	45	115	−20 −30	None.
.....	.....	875	Driven wells; some flowing.	100±	25	150	30	145	+ 5	Strong.
'ity....	1,122	829	Driven wells.....	90	15	223	165	.....	− 6	
fill....	.....	860 900	....do.....	.....	10	60	25	25	−10	Fair size.
.....	.....	870 885	....do.....	100	4	114	60	60	+14	Do.
›ra.....	313	±1,050	....do.....	.....	30	120	.....	100	.....	Large.
Branch.	654	830 795	Driven wells, with flows in valleys near village.	200	30	250	65	60	−20	
ake....	212	868	Driven wells: lakes.	.....	10	50	20	20	.....	
ood....	.....	810	Flowing wells....	50	38	50	40	38	+ 2	

FLOWING WELLS.

ATTICA TOWNSHIP.

One well in the south part of Attica Township (T. 7 N., R. 11 E is reported by the driller, George H. Force, to flow 18 gallons a mi ute from a 2-inch pipe. The water is from gravel. This is in a lo tract leading northwest and southeast between moraines, and oth flows may be obtained in it.

LUM.

The village of Lum stands on the inner or iceward slope of a morain belt at the border of a low swampy tract in T. 8 N, R. 11 E. At th border of the higher land on which the village stands, two flowin wells have been obtained, one a few yards south of the railway statio on ground 4 feet lower or 867 feet above tide, made by Willia Bentley, the other at the condensed milk factory about one-eight mile southwest of the railway station at about the same altitude a the station. They were made about 1895. Each enters rock a fe feet, and the water is not so hard as water from wells in the glaci deposits. They differ slightly in temperature, the Bentley well bein 49.5° F, and the milk factory well 50°. They differ also a few fe in depth, the Bentley well being 116 feet and the other 104.5 fe The milk factory well is stronger in iron than the Bentley. Th original head of the Bentley well was 15 feet, but it may not be so gre at present. The rate of flow has greatly diminished, and is now b 5 quarts a minute. The milk factory well flows still less or about quarts a minute. The wells were largely through blue till. Th rock is apparently sandstone.

The extent of this pool has not been tested, but it seems probabl that flows may be obtained along the low ground both to the nort and to the southeast of the village if the wells are carried to the roc Possibly the drift will yield flows, for the elevated land south and we of the lowland should give high pressure to waters that pass into and flow toward the lower country on the northeast.

Wells at Lum (T. 8 N., R. 11 E.).

Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
		Feet.	*Inches.*	*Feet.*	*Gallons*	*° F.*	
Wm. Bentley	1895	116	2	+15	5	49.5	Water soft with little iron.
Milk condensing factory.	.....	104½	2	+ ?	3	50	Strong in iron and harde than Bentley well.

BURNSIDE TOWNSHIP.

This pool embraces a group of about 12 wells, of which nine ar in the village of Burnside in secs. 8 and 9, T. 9 N., R. 12 E., two abou one-fourth mile east of the village near the line of secs. 9 and 1 and one about 2 miles southeast in the southwest part of sec. 1 Some of those in the village have now ceased flowing. They are a

ated on the northeast or iceward slope of a morainic belt which her west lies immediately north of the Imlay outlet of Lake umee. It is probable that flows may be obtained along this der southeast from Burnside as far as the most remote well (in . 15) and possibly farther, but to the north and west from Burn- e the head is insufficient to give a flow. Those in the village are ng a small stream 3 to 5 feet below the general level. The moraine ng west and south of this district is the probable catchment area the shallow wells, but the catchment of a deeper well at the rnside creamery is not easily determinable.

The earliest flows were obtained about 1875, and the majority ve been made twenty years or more. They are all shallow drift lls with depths of 20 to 60 feet, except one at the Burnside cream- y, which has a depth of 159.5 feet and extends about 50 feet into ck. The drift is chiefly a blue clayey till with thin beds of sand d gravel. The largest flow is on the farm of Fred Buby, 2 miles utheast of Burnside in the SW. ¼ sec. 15. It was bored 20 feet rough clay to the water-bearing gravel and a hollow log used as a nstock was inserted in the boring, giving a pipe of about 12-inch side diameter. It flows about one-half barrel a minute, and has en running since 1876. The water is hard in all the wells, including e creamery well, which gets its supply from the rock. This well s less iron, however, than the shallow ones, the latter being strong iron. The head in most of the wells is less than 3 feet, and two of em have to be piped to lower ground in order to flow. One well, wever, on the Webster farm, one-fourth mile east of the village, ws a good stream from a pipe that stands 3½ feet above the surface d is said to have a head of 7 to 8 feet. This is perhaps on ground ough lower than the other wells to give the difference in height ove the ground, though no leveling was made to test the matter.

Wells at and near Burnside (T. 9 N., R. 12 E.).

Section.	Quarter.	Owner.	When made.	Depth.	Diameter.	Flow per minute.	Temperature.	Remarks.
				Feet.	*Inch.*	*Galls.*	*° F.*	
15	SW.	Fred Buby	1876	20	12	20	(?)	Entered gravel at bottom.
16	NW.	Joseph Kohler	1875	25	36	1	49	Dug 12 feet, bored 13 through clayey drift.
9	SW.	Daniel Webster	1901	66	2	1½	50.3	Head about 7 feet.
		Peter Miller, Burnside.	1892	37	(?)	.....	.....	In sand from 21 to 27 feet; no flow.
		Burnside Creamery	1899	159½	2	1	49.5	Flow from rock.
		Blacksmith shop, at Burnside.	1891	37	2	.....	.....	Largely through clay; flow weak.
		Wilcox Hotel	(?)	37	2	.....	(?)	Water is piped to lower ground to get flow; very weak.
		Lot adjoining hotel on north.	.....	37	2	.....	.....	Piped to lower ground to flow.
		JosephShotwell,Burnside.	1884	37	2	.....	.....	Stands in pipe near level of ground.
		Mr. Howe	1903	37	8	.....	48.5	Overflows from a tile into pool; all clayey drft except thin sand bed near bottom.
		E. Y. Koyle	±1880	40	2	.....	.....	Well now choked.
		Thos. Clement	(?)	± 40	2	.....	.....	Has stopped flowing.

NORTH BRANCH DISTRICT.

There are two groups and possibly two distinct pools en in the flowing wells near North Branch, as indicated in fig. 31 group is in the Imlay outlet south and west of the village, other in a sag on the north side of a moraine that lies nortl Imlay outlet, and leads from the village eastward along the of North Branch and Burlington townships. The wells are in both groups, the majority being between 16 and 40 feet in The group east of North Branch seems favorably situated to its supply from the morainic ridge on its south border, but th in the Imlay outlet stands outside the moraine, and its cat area is a matter somewhat difficult to settle. The outlet h a few feet of stiff clay at surface, which forms a good cover t

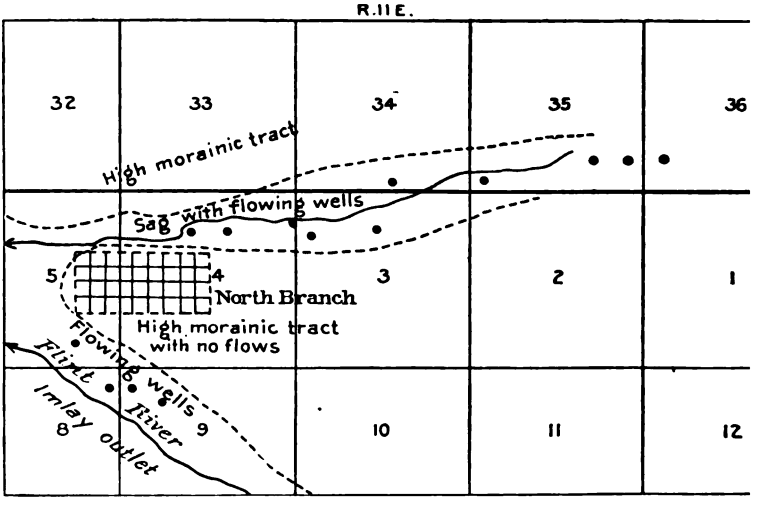


FIG. 31.—Flowing wells near North Branch, Lapeer County.

that may come in either from the north or south borders deposits are more porous, as well as at higher levels. The o mode of deposition of this clay in the outlet is a matter of som tainty. At surface it appears to be a water deposit such a be laid down in a pool in the old lake outlet, but exposu scarcely sufficient to make certain that this is its character t out, nor are they adequate to reveal the extent of the deposit relation to undoubted glacial deposits each side of the out the sag back of the moraine the wells penetrate a clayey till on passing southward into the moraine, graduates into a more till with pockets or intercalated beds of sand and gravel, an itself contains thin beds of sand that furnish the supply to the wells. A deep well on the moraine at the North Branch light plant which obtains its supply from glacial deposits at

of 150 feet, has a water level 50 feet below the surface, or 20 to 30 feet less than in the flowing wells. This rather exceptional feature may be due to difference in the catchment area, that for the flowing wells being, as above suggested, from higher land in the immediate vicinity, while that for the deep one is from a more distant source.

Wells in North Branch district.

IN IMLAY OUTLET, NORTH BRANCH TOWNSHIP, ALTITUDE 790 TO 795 FEET.

Location.	Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
			Feet.	*Inches.*	*Feet.*	*Gallons.*	*° F.*	
NE. corner sec. 8..	G. R. Cobb.....	1884	24	2	5+	5	49.3	Chalybeate; hard.
SE. corner sec. 5...	F. S. Porter.....	1888	16	2	5+	Choked.	.....	Do.
Center sec. 5.....	S. Porter.....	1886	20	2	5+	Strong.	.....	Do.
NW. corner sec. 9..	Mrs. Fannie Coffen (2 wells).	1896	20	2	5+	(?)	.....	Do.
		1896?	20	2	5	(?)	.....	Do.

IN SAG NORTH OF MORAINE, ALTITUDE ABOUT 800 FEET.

Location.	Owner.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
		Feet.	*In.*	*Feet.*	*Galls.*	*° F.*	
½ mile north of North Branch station.	D. McCurdy.....	(?)	(?)	(?)	(?)	(?)	
½ mile north of station.....	R. Stafford.....	33	(?)	(?)	(?)	(?)	
N. side sec. 3 North Branch Township.	J. Crocker.....	35	1.5	+ 1	.....	48.8	Flows 1-inch stream.
NW. part sec. 3, North Branch Township.	J. Hayes.....	35	1.5	+ 1.5	.....	.....	
SW. part sec. 34, Burlington Township.	T. McLaughlin ...	.....	.....	.....	.....	.....	
SW. part sec. 35, Burlington Township.	Wm. Coffen.....	26	.....	.....	.....	.....	
SE. part sec. 35, Burlington Township.	T. Fitz Stephens..	23	.....	.....	.....	.....	Choked.
SW. part sec. 36, Burlington Township.	W. Slatterly.....	53	.....	0	.....	.....	
				+ 3	.....	.....	
SW. part sec. 36, Burlington Township.[a]	.....do.....	165	3	−20	.....	.....	Rock at 135 feet.
North Branch electric-light plant.[b]	.....	250	6	−50	(c)	.....	Rock at 200 feet.

[a] Altitude, 825 feet.
[b] Rock at 200 feet, main water supply at 150 feet from gravel, also supply at 75 feet; altitude 817 feet.
[c] Yields 1,000 barrels a day by pumping.

CLIFFORD.

In a low tract, back of a morainic ridge south and west of Clifford station, flows are likely to be obtained at shallow depths. At present but one boring has been made that throws light upon the conditions, that of Mr. A. Harvey, in the old village of Clifford, one-half mile south of the present village. This boring struck a flow at 16 feet, but it was not utilized.

SILVERWOOD DISTRICT.

This flowing-well district, as indicated in fig. 32, is spread over an area of 6 or 7 square miles, mainly in Rich Township (T. 10 N., R. 10 E.), Lapeer County, but touches the northwest corner of Burlington Township (T. 10 N., R. 11 E.), Lapeer County, and the southeast

corner of Dayton Township (T. 11 N., R. 10 E.), Tuscola County. The village of Silverwood, at its north border, has given the name to the district. The wells are located on a plain at the south border of the Marlette moraine, and at an altitude of 75 to 100 feet or more below the level of the crest of the moraine. The altitude of Silverwood station, on the Pere Marquette Railroad, is 807 feet. Water stands 2 to 4 feet below the surface in wells in the village at the altitude of the station, flows being obtained only on ground less than 805 feet above tide. The altitude seems to be a few feet less, or about 790 feet above tide, in the southern part of the district, though only barometric measurements were made.

A remarkable feature in this district is the apparent rise in head from south to north, a feature which suggests that the Marlette moraine is the catchment area rather than districts to the south. Yet this district is outside the Marlette moraine in a situation that would be fed by it only under exceptional conditions. Ordinarily the waters falling upon a moraine find underground courses toward the inner border plain rather than into districts outside. In order to have a movement into an outer border district the beds through which the waters find passage should descend toward that district. This might occur if the drift sheet is laid down on a rock surface that becomes lower in passing from the moraine to the outer border district, and this is probably the case in this district. From the few records of borings obtained there appears to be a tract of lower rock surface and thicker drift south of the Marlette moraine in Lapeer County than along the moraine. In the vicinity of the Marlette moraine, rock is struck at about 750 to 775 feet above tide, but a few miles south it is 50 to 150 feet lower. This higher altitude of the rock surface, rather than an exceptional thickness of drift, seems to be the cause of the prominence of the moraine, while a low rock surface, rather than a thin deposit of drift, is responsible for the low altitude in the

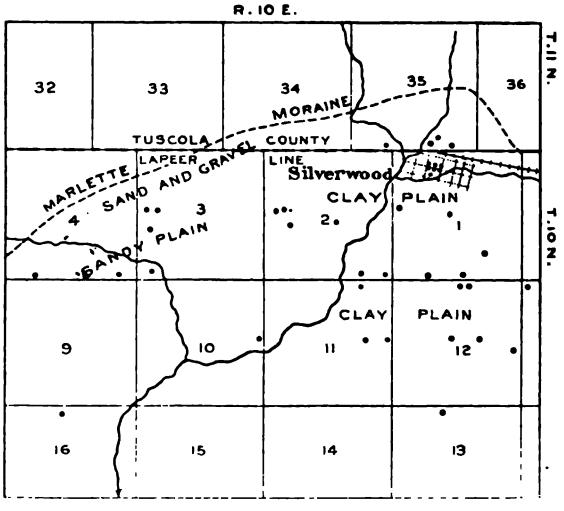


FIG. 32.—Distribution of flowing wells in and near Silverwood, in Lapeer and Tuscola counties.

part of Lapeer County between this moraine and the Imlay outlet In general, borings show 100 to 200 feet of drift in the vicinity of this outlet on ground 775 to 825 feet above tide, while on the moraine, at altitudes of 825 to 900 feet, rock is reached at 50 to 100 feet. There seems, in this condition of the bed-rock surface, to be sufficient cause for at least part of the water falling on the moraine to take a southward course beneath the outer border plain Another condition which would perhaps tend in the same direction is that of the building of the Marlette moraine by a halt rather than by a readvance of the ice sheet, so that beds low down in the moraine would continue into the plain outside. Indeed, there are features which suggest either the persistence of stagnant ice or the presence of a lake on the plain outside the Marlette moraine while that moraine was in process of deposition. It is found that the outwash from the moraine does not cover certain low parts of the outer border district, such as that at Silverwood, while it does cover parts to the east and west of this village. The Marlette moraine may therefore, on the first supposition, be contemporaneous in time of deposition and a continuation of the surface portion of the drift in the outer border district, rather than the edge of an overlapping drift sheet.

Between 40 and 50 flowing wells have been obtained in this district but in some cases the owners have found it difficult to dispose of the surplus water by removal through ditches, and have not attempted to devise or to put in use any apparatus for shutting off the flow, but have, instead, attached pumps with spouts too high to permit a flow, and thus lost the advantage of this class of wells In a few cases, however, the flow has become so weak that a pump was attached. Some of the wells have been flowing a good stream for about thirty years, and the majority have been flowing so long that the owners do not recollect the date of their drilling. They have, commonly, 1½ or 2-inch pipes, or less. The depths are between 20 and 45 feet, and the water supplies are obtained from beds of sand or gravel, usually below blue clay. In some cases there is a surface sand of slight depth above the clay. The water is, as a rule strong in iron and rather hard. It carries only enough salt to be detectable to the taste, and never enough to be objectionable. The waters are popular and are preferred by the residents to "surface water" obtained at less depth.

The following list is incomplete in data on certain points owing to a failure to find the persons at home who made the wells. An attempt to supplement the information by correspondence has brought in but few returns, most of the letters remaining unanswered

Wells in Silverwood district (Tps. 10 and 11 N., Rs. 10 and 11 E.).

Location.	Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Quality.	Remark
			Ft.	*In.*	*Feet.*	*Gallons.*	*°F.*		
Water tank of Pere Marquette R. R., Silverwood.	.....	(?)	48	4	+2	42	49		
Brickyard, Silverwood.	.....	(?)	40	.75	+1.5	1	49		
Blacksmith shop, Silverwood (7 wells in and around shop; 3 now in use).	.....	(?)	30	2	+1	All weak.	....		
Silverwood	A. Johnson	.....	48	2	+1	Strong.	49		
Sec. 35, Dayton Township.	Matilda Cowles	1888	36	12	Lowering.	Weakening.	(?)	Hard; iron.	
Sec. 7, Burlington Township.	J. Frank Mitchell	1901	25	2	(?)	Strong.	(?)		
Sec. 1, Rich Township.	Wm. Kincaid (2 wells).	.....	25	.....	.....	.....	....		
Do.	Mrs. Henry Sypher.	.....	.....	.....	.....	.....	....		
Do.	Levi Ayres	1903	.....	.....	.....	.....	....		
Do.	George Cowles	1890	50	2	.....	10	49	Iron; medium.	
Do.	E. Losh	.....	37	2	.....	.....	....		
Sec. 2, Rich Township.	Henry Sypher	.....	.....	.....	.....	.....	....		
Do.	James Vasbinder	1879	45	2	.....	1½-inch stream.	(?)	Hard; iron.	Some w at 24 f rock (? bottom
Do.	Schoolhouse	.....	.....	.....	.....	.....	....		
Do.	D. G. Smith (2 wells).	1886 1886	45 45	1.5 1.5	+2 +4	1 Strong.	49 (?)	....	At resider Well in pond.
Do.	Claud Cowles	.....	.....	.....	.....	.....	....		
Sec. 3, Rich Township.	James Seddon	.....	.....	.....	.....	.....	....		
Do.	Henry Seddon	.....	.....	.....	.....	.....	....		
Do.	McIntyre estate	.....	.....	.....	.....	.....	....		
Do.	Mrs. Bacon	.....	.....	.....	.....	.....	....		
Sec. 4, Rich Township.	McIntyre estate	.....	.....	.....	.....	.....	....		
Do.	D. Huntley	.....	.....	.....	.....	.....	....		
Sec. 10, Rich Township.	Mr. Deming	.....	.....	.....	.....	.....	....		
Sec. 11, Rich Township.	Jacob Bush	1874	.....	.....	.....	.....	....		
Do.	Charles Sypher	.....	.....	.....	.....	.....	....		
Sec. 12, Rich Township.	M. L. Rowell (2 wells).	1884 1894	40 25	2 2	+1 +4	Weak. 4.5	49 49		
Do.	Horace Lyman	.....	.....	.....	.....	.....	....		
Do.	Walter Anderson	.....	.....	.....	.....	.....	....		
Do.	E. McGough	.....	.....	.....	.....	.....	....		
Sec. 13, Rich Township.	Emerson Wilson	.....	.....	.....	.....	.....	....		
Sec. 16, Rich Township.	John Hodge	.....	.....	.....	.....	.....	....		

COLUMBIAVILLE DISTRICTS.

The flowing wells near Columbiaville are not all in one distr those in Flint River Valley being separated from those a mile w of the village by a till ridge. There are two wells in the valley Columbiaville on the Peters estate, and one 5 miles below Columl ville at a farmhouse. One in the north part of the village is ab 80 feet deep and 2 inches in diameter, with a 1-inch escape p This well throws a jet 8 feet high from the 1-inch pipe, which c for a discharge of about 55 gallons a minute. The water is fi

and under a stiff blue clay. The other well is 4 inches in diameter and about 1,500 feet deep, but the supply of water is from comparatively slight depth. The head is 28 feet above the surface, or about 780 feet above tide, and the discharge is reported to be several barrels a minute.

The well 5 miles below Columbiaville is on a terrace south of Flint River, 35 to 40 feet above the low-water level, and flows a weak stream. The well is about 60 feet deep.

One of the wells a mile west of Columbiaville is at the residence of George Jerome, in the SE. ¼ NE. ¼ sec. 29, T. 9 N., R. 7 E. (Marathon Township). It is 62 feet in depth and 2 inches in diameter and has a head of 6 feet. It flows a small stream three-fourths inch or less. The well was made about 1893, and is mainly through blue clay.

The other well, a mile west of Columbiaville, is only a few rods south of the Jerome well, in the NE. ¼ SE. ¼ sec. 29, at the residence of W. Sanford. It was made about twenty-five years ago, and flows a half-inch stream from a 2-inch pipe. The drift is about 80 feet thick.

WATER SUPPLIES OF NORTHERN CLINTON COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Clinton County two towns having public supply, Ovid and St. Johns, and the several flowing-well districts of the northern half of the county were examined. The district near Elsie, however, was assigned to Mr. Davis, and is therefore discussed by him.[a] One of the flowing-well districts, the Eureka, extends into southern Gratiot County, but is discussed as a whole in this place. The southern half of Clinton County is discussed by Doctor Lane as a part of the region bordering Lansing (pp. 170–175).

FLOWING WELLS.

EUREKA DISTRICT.

The Eureka district occupies several square miles on the borders of Clinton and Gratiot counties, in Greenbush and Washington townships, and represents almost typically that relation between moraines and drainage which results so frequently in artesian flows. The descent from the summit of the bordering moraine (fig. 33) is steeper in passing down to the edge of the plain than the slope farther north across the plain toward Maple River. Sec. 34 and the southern part of sec. 27 have imperceptible slopes and imperfect drainage. Near Maple River and its larger tributaries there is some-

[a] See pp. 230-233.

what stronger relief, but in general the district is flat. As sho in the following table, there is a steady increase of head to the sou west of the area of flow in the direction of the moraine, from wh the artesian supply is apparently derived.

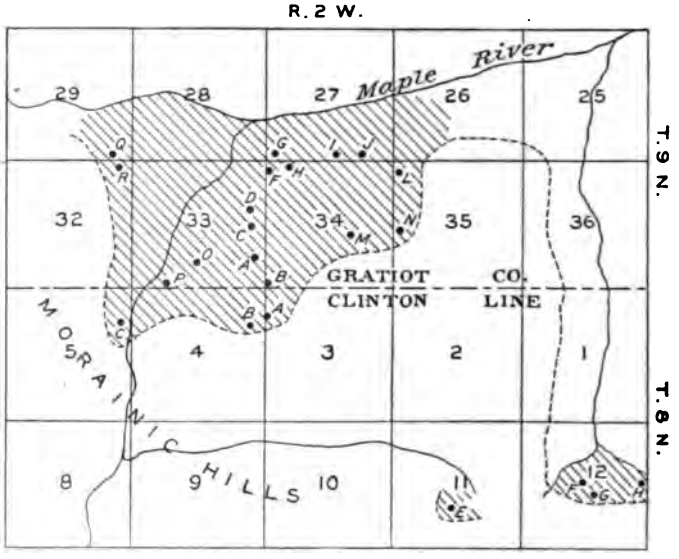


FIG. 33.—Map showing Eureka flowing-well area in relation to drainage and moraine. The kn area of flows is shaded, but flows may be obtained north of Maple River.

The Eureka flows are not confined to the stream valleys, but distributed over the plain. The first flowing well in the area sunk in 1865, and the development has continued steadily to present, a length of time that affords unusual opportunities for determination of the effect of flow on the head. Many of the w show a decrease of supply not altogether due to the clogging of pipe. Mrs. Youdan's well furnishes at present but one-eighth gal a minute, whereas its yield when first put down was 5 gallons a n ute. A similar decrease is noted in W. W. Williams's well. P Zigler reports a decrease of 9 feet in the head of his well, which is feet deep. The decrease affects deep and shallow wells alike. S sonal fluctuations in head and flow are noted, these being in fl from sources no deeper than those at Eureka.

The following sections indicate the nature and relations of water-bearing material:

Record of Wilson Keiser's well, Eureka.

	Thickness.	T
	Feet.	F
Clay, with thin layers of water-bearing sand, one at 40 feet yielding a slight flow.	55	
Sand and gravel	5	

Record of Edward Burke's well, Eureka.

	Thickness.	Total.
	Feet.	*Feet.*
nd hardpan	99	99
ay	2	101
(?).		

Record of W. C. Bailis's well, Eureka.

	Thickness.	Total.
	Feet.	*Feet.*
clay	90	90
and gravel.		

ı secs. 11 and 12, Greenbush Township, are two areas smaller than one just discussed. These occur at the heads of smaller tributary ams, and in the valley of the stream which joins Maple River in 25 there occurs what is probably a continuation of the area of s found farther west.

o flows are reported on the north side of the river, and none are ly to be found there, on account of the rapid slope from a moraine g near by.

Wells in Eureka district.

Section.	Township N.	Range W.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Feet.	*Feet.*	*Feet.*	*Galls.*	-F.
12	8	2	Ed Burke	1900	175	696	696		
12	8	2	Gilbert Beck	1899	147	688	686		
12	8	2	Fred Russell	1896	190	686½	687½		
11	8	2	Eureka village			725	728	1.75	55.7
11	8	2	S. Burrows	1898	196	701			
3	8	2	Saml. Strauser			683	687	.25	53.4
4	8	2	M. A. Youdan	1894	94	685	689	.12	56.2
5	8	2	D. J. Virrfith	1903	124	693	695	1	51.8
33	9	2	C. S. Patterson	1874	35	682	685	.11	53.8
34	9	2	E. Darling	1865	30	683	686	.5	51.2
33	9	2	E. Weatherby	1894	70	681	686	1.25	52.1
33	9	2	Fred Keiser		22	684	689	2	49.5
34	9	2	P. C. Zigler	1889	27	677	680	.5	51.5
34	9	2	W. Church	1903	109	677	685	12	52.7
27	9	2	W. C. Baylis	1904	90	680	700	2	51.3
34	9	2	W. Church	1903	109	676	684	15	52.7
27	9	2	S. A. Miller			680	686	3	51.2
27	9	2	B. K. Stormfeltz	1888	33	680	685	1.25	52.5
35	9	2	W. Keiser	1901	65	692	697	1.5	50.9
34	9	2	C. Brewbaker	1884	56	690	693	.25	52
35	9	2	J. E. Walker			700	705	.75	51
33	9	2	W. W. Williams	1888	100	675	683	1	52
33	9	2	J. Zigler	1890	95	680	689	3	51.5
24	9	2	A. B. Baum	1903	50	673	674	1	51.8
32	9	2	L. Lohrer		50	673			

e diameter of the pipes is uniformly 2 inches.

MAPLE RAPIDS DISTRICT.

In a test boring for coal at Maple Rapids, where the surface elevation is 640 feet above tide, a strong flow of water was obtained from three different horizons, as shown in the following section:

Record of coal boring at Maple Rapids.

	Thickness.	Total.
	Feet.	*Feet.*
Hardpan	25	25
Blue clay	3	28
Stones	8	36
Blue clay	28	64
Hardpan	5	69
Sand with water	1	70
Blue clay	6	76
Sand	1	77
Brown clay	7	84
Gravel	2	86
Red sand with water	82	168
Gray rock	14	182
Red sandstone	2	184
Dark shale	31	215
Red shale	3	218
Soapstone	29	244
Light shale	17	261
Coal	1	261½
Light shale	33½	295
White sandstone with water	39	334

About 2 miles east and three-fourths of a mile north of Maple Rapids, in the NW. ¼ sec. 3, T. 8 N., R. 3 W., is another flowing well that is supplied from the drift. It is located at the foot of a bluff which represents the southern valley side of Maple River. The height of the bluff as determined by aneroid is 75 feet, an unusual height, due to the fact that Maple River here crosses the St. Johns moraine. The bluff maintains this height for a half mile up and down the valley, and for this distance flows dependent on local relief may fairly be expected to occur.

The owner of the well is Zalmon Wyman; the driller, Barney Norton, of Maple Rapids. The depth is 31 feet, diameter of pipe 2 inches, temperature 52° F., altitude 660 feet, head 10 feet, flow 1.5 gallons a minute. The well was drilled in March, 1903, and has since yielded a constant supply of water, which is derived from gravel underlying 30 feet of gravelly clay or till, and is used for domestic purposes.

ST. JOHNS DISTRICT.

One mile northeast of St. Johns, near the source of Spring Brook, are the two flows first mentioned in the table below. They are obtained at a slight depth in gravel and sand underneath a layer of clay about 10 feet thick. The flows are supplied from the St. Johns moraine, and both are on the floor of the valley of Spring Brook. Flows farther down the valley are unknown, and farther up the valley the summit of the moraine is quickly reached. The water in bot-

wells is hard and chalybeate and is used for ordinary farm purposes. In addition to this the water in the well belonging to the Spring Brook Ice Company is collected in an artificial pond about 2 acres in extent, from which most of the ice supplied in St. Johns is cut.

A low dam and sluice gate permits the regulation of the height of water. Each summer the pond is drained and the bottom plowed, effecting thorough aeration, this being necessary because of the coating of iron oxide deposited from the chalybeate water.

Northwest of St. Johns, in the valley of another small tributary of Spring Brook and in the same relation with reference to the St. Johns moraine, is another small group of four flows. As shown in fig. 34, these occur in close association with the drainage, as they must in this locality, where the relief, though slight, is sufficient to prevent flows except along the stream courses. The character of water and the direction of flows are similar to those in the preceding group. Mr. Feightling has constructed a trout pond which is fed by the overflow from his well, and he intends to install a hydraulic ram for supplying his house with water. The other wells of this section are put to ordinary domestic and farm uses.

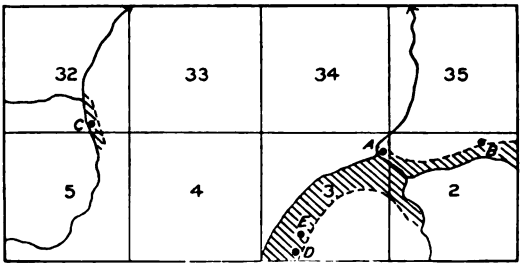


FIG. 34.—Flowing wells near St. Johns, Clinton County.

Still farther northwest, in sec. 32, T. 8 N., R. 3 W., on the next western tributary of Spring Brook, is the flowing well of R. T. Ferguson. The well is at the top of the bluff above the little stream just mentioned. The water rose to within 18 inches of the surface and by piping to the ravine 200 feet away a flow was secured. Since this method is used to secure flows in a number of places, a diagram (fig. 35) is given illustrating the relations.

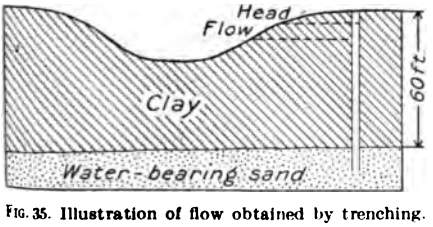


FIG. 35. Illustration of flow obtained by trenching.

Mr. Ferguson has built his barn below the flow and installed a system of pipes so that the water runs by gravity through the basement. This combination of slope and flow might in many other cases be utilized to the great saving of money and labor.

Between this well and the group east of here the surface is very level, especially in the western part of the area. The water rises in all the dug or driven wells with strong artesian effect, standing in many cases but a few inches below the surface, and is never more than 10

feet below it. But in tracts lying between the stream valleys flows are not obtained.

Wells in St. Johns district.

Letter on fig. 34.	Section.	Township N.	Range W.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
						Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*
C.	9	7	2	Spring Brook Ice Co	1895	20	751	756	10	51.1
D.	4	7	2	T. L. Stewart	.....	.....	726	727	3	51.2
A.	3	7	3	George Feightling	.....	70	708½	712½	8	51.2
B.	2	7	3	John Matter	1898	92	713	712	.....	.....
D.	3	7	3	H. V. Hostetler	1901	96	711	714	1.5	51.7
E.	2	7	3	.....do	1892	40	705	706	.12	66?
C.	32	8	3	R. J. Ferguson	1902	91	707	709	.33	52.6

SHEPARDSVILLE DISTRICT.

One mile south of Shepardsville in Ovid Township (T. 7 N., R. 1 W.), in western Clinton County, is the flowing well of E. R. Munson. It is at an altitude of 716 feet. The water at present is just level with the surface, but has fallen 8 feet since the well was sunk about forty years ago, the loss being probably due to clogging of the pipe. The flow is 1.5 gallons per minute, and the temperature 49.5° F. The water is strongly chalybeate. The following section was furnished by Mr. Munson:

Record of Munson well, Ovid Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	14	14
Quicksand	2	16
Blue clay	7	23
Water-bearing gravel.		

Other attempts to secure flows in the valley of Maple River near Shepardsville have been made on slightly higher ground and have proved unsuccessful. One-half mile southwest of Duplain in the same valley, but in another township, is another flow belonging to A. M. Birmingham. It is located within a few feet of Maple River at an altitude of 713 feet. The water is unusually soft and comes from a water bed 20 feet below the surface and beneath blue clay.

ELSIE AND VICINITY.[a]

Elsie is situated in northeastern Clinton County in T. 3 N., R 1 W., on a low, gravel-covered ridge, sloping on the north to the Ann Arbor Railroad, on the south to the valley of a tributary of Maple River,

[a] By Charles A. Davis.

ıd on the west to Maple River. The ridge, in part at least, is the sult of wave action on the shore of the Glacial Lake Saginaw. ence it is porous, and since it is superposed upon a clay substratum ; no great depth below the surface water is easily obtained.

The wells in the town are generally shallow, some probably too nallow for the safety of those who use the water. On the north de of town they are from 7 to 20 feet deep; those on the top of the dge are somewhat deeper—35 feet and more. The tile well is comıon, and this type of construction seems popular in some parts of ne village. It is certainly less objectionable than the older type of ug wells.

There is no public supply at present, and so far as learned none is ontemplated, but eventually the town will need fire protection at ast, and for this purpose Maple River is the nearest available source. 'his stream would not furnish a supply of water which would be ecommended for any purpose except sprinkling and fire protection, nd if drinking water were sought, wells would have to be developed. 'he most accessible place for putting down test wells would be in he lowest part of the river valley, within easy reach of the village, rhere a good supply of water would most probably be found. Wells n the vicinity of the railroad station might yield also sufficient water. Another possible place for the location of a pumping station would e at a powerful flow of water from the ground beside the railroad racks 1¼ miles southeast of the village. Explorations in this neighorhood would probably yield other flows that would furnish a large quantity of excellent water, which could be pumped to town.

There are no flowing wells in Elsie village, but in other parts of Duplain Township there are two districts with shallow yet strong-flowing wells. One of these lies in a drainage valley on the eastern side of sec. 1. It contains but a single well, but is apparently capable of further development. Several farms along the valley could probably get good supplies of flowing water if the wells were put down at the lowest points. The present well has been in existence for twenty years at least and flows a large stream of excellent water at the present time.

The other and principal area lies south of Elsie, beginning about 3 miles south and extending several miles in a southeasterly direction, the area seeming nearly coincident with the shallow valley of one of the small tributaries of Maple River. It is bounded on the west by a small, sharp, morainal ridge 30 to 50 feet high, which runs nearly north and south at its northern end and trends southeastward in its southern part.

Within this area large flows are so easily obtained by boring with a common earth auger that many of the farms have several wells, running in the aggregate enough water to supply the needs of a small

town. The cost of putting the wells down is said to be from $3 to $5, including labor, and the depth ranges from 8 to 25 feet.

The usual way in which these wells are piped is to bore a 1¼-inch hole lengthwise through a common fence post, then start the boring into the earth at the bottom of a hole a little smaller than the post and about the depth of an ordinary post hole. When water is reached, the post is driven into the hole. The head is frequently sufficient to drive the water out through the hole in the post; if it does not, the next step, after the post is set, is to bore a lateral hole through into the central one near the upper limit of the head, or at such point as may be desirable, and into this drive a spile of simple construction, through which the water is delivered. If the head lowers, the spile is easily lowered, and in this way fairly exact records of lowering of some of the wells may be had, some posts showing several successive orifices of this kind.

The small ridge to the west is hardly large enough to furnish such a great quantity of water as flows from the larger wells, and it seems probable that the more extended rolling country to the south is the source of supply.

Near the bottom of the embankment of the Ann Arbor Railroad 1¼ miles southeast of Elsie, in a marshy tract at the foot of a long slope from the north, is a fine spring, the overflow from which runs off as a stream a foot wide and 2 inches deep. The water comes up through a barrel and rises 6 inches above the surface of the ground about the spring from clean gravel and sand at the bottom. One informant said that this was merely a hole made by pushing a fence rail down into the ground 6 or 8 feet and breaking through the hard-pan. The general character of the ground about the spring would indicate, however, that there have been natural springs in the neighborhood for some time, however this particular one originated. The altitude is about 715 feet, and the temperature of the water 48° F.

A well three-fourths of a mile south of Elsie on the west side of sec. 13, Duplain Township, is reported as about 200 feet deep, with rock at 98 feet. The water rises within 2 feet of the surface at the house, and flows one-half gallon a minute at a watering trough 3 feet below the level of the pump. This well is near the valley of the stream south of town and is about 12 feet below the village, or 725 feet above tide. South of Elsie the rock surface is said to be from 100 to 130 feet below the surface, but a mile or two to the north it is quite variable, running from 27 to 175 feet or more in depth within short distances. This information was given by Mr. Otto Heinze, a well driller who has worked in the region several years.

Wells in Elsie district (T. 8 N., R. 1 W.).

	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
			In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*		
1	Unknown [a]	1884	3	20	715	+ 3	10	48.5	Hard; iron.	Gravel.
25	Ezra Waite [b]		1.5	18	712	+ 5	2–3	48.5	.....do.....	Do.
25	E. Bensinger [c]	1904	1.25	16	715	− 5	2	48.8	.....do.....	Do.
30	E. Munson [d]		1.5	19	712	+ 2	1.5	49.5	.....do.....	Do.
25	G. W. Bowers [e]	1874	2	22 16	725	+ 3	8+	48.2	.....do.....	
36	J. Bensinger [f]		2	23	720	+2–5	1–3	.....	.....do.....	
25	G. W. Bowers [g]		2	20	718	+ 2	4	48.5	.....do.....	
25	H. M. Jeffrey [h]	1884	2	22	725	+ 3	6	50	.....do.....	

[a] Bored and never piped, except by pump log driven through the soil; fine flow.
[b] In corn field; not cased.
[c] Bored log with spigot in side. Yellow clay 12 feet, blue clay 4 feet, water gravel. Rock at 30 feet probably a bowlder in pump well near by.
[d] T. 8 N., R. 1 E. Shows on post three successive lowerings from a head 2 feet higher than present.
[e] Largest of group; great waste of water.
[f] Mr. Bensinger has four wells from 16 to 23 feet deep.
[g] Stock well at north end of farm.
[h] Supplies a public trough on road from Elsie to Ovid.

WATERWORKS.

OVID.

The village of Ovid is in Ovid Township, on the eastern border of Clinton County, near the headwaters of Maple River. The surface is gently rolling, being an intermorainic area of slight relief.

The water system is operated in connection with an electric-light plant, and both are controlled by the village. The former was established in 1888, the latter in 1894. Water is drawn from a curb well 20 feet deep and 16 feet in diameter. The stand tower is 70 feet high and holds 1,300 barrels, 2,000 barrels being the average daily amount supplied.

Ten or twelve years ago oil was used for fuel in running the engines. This was stored underground in a large tank, and, a leak having formed, the public water became polluted. Two or three years were required to purify the oil-sodden earth, during which time the water could not be used.

ST. JOHNS.

Admirable drainage is secured for St. Johns by the slopes on which it is built, and which, while weak for a moraine, are still strong enough to give a pleasing variety to streets and grounds—an important factor in the growth of a town.

From the notebooks of James B. Henderson, superintendent of waterworks, accurate data were secured as to the depths of the different wells and the material penetrated. The 5 deep wells supplying the village are located in a group with intervals of 6 feet, and have the following depths: 222, 312, 544, 548, and 574 feet. The

cost of the wells was $2 a foot, the village furnishing the casing. The section of the deepest well is as follows:

Record of waterworks well, St. Johns.

	Thickness.	Total.
	Feet.	*Feet.*
Clay with thin layers of quicksand	40	[illegible]
(This indicates the depth of the moraine at St. Johns. There was a heavy water bed at 28 feet, but the supply was too near the surface to be considered safe.)		
Coarse gravel	112	[illegible]
Red sandstone, bearing some water	20	[illegible]
Blue shale	202	[illegible]
Black shale with alternating hard and soft layers	1	[illegible]
White water-bearing sand rock (Parma)	150	[illegible]
Gray water-bearing sand rock	10	[illegible]
Black shale	15	[illegible]
Blue shale	24	[illegible]

Water is drawn from the first and second sandstones. The water stands at 40 feet below the surface, or 713 feet above tide; by pumping with forced draft it can be lowered 85 feet, or to 125 feet below the surface. It is pumped into two brick reservoirs 19 feet deep and 27 feet in diameter, together holding 150,000 gallons. The average daily amount supplied to the village is 275,000 gallons, over 80[illegible] families and all the steam plants in town making use of the public supply.

The quality of the water, as determined by chemical analysis made by Thomas Cooley, of the University of Michigan, August 5, 1904, is as follows:

Analysis of water of St. Johns waterworks.

	Parts per million.
Total residue obtained by evaporation at 110° C.	446
Residue after ignition, or inorganic matter in residue	312
Organic residue, or loss on ignition	134
Chlorine (as sodium chloride)	38
Sulphates (as SO_3)	Trace
Potassium permanganate reduced by organic matter in the water	12.1
Free ammonia	.0[illegible]
Albuminoid ammonia	.0[illegible]
Nitrates	0
Nitrites	0

Color, clear; odor, none; reaction, neutral; no appreciable deposit; no germs except ordinary water germs; inoculation experiment negative. This is a very fair water, perfectly safe for domestic use in its present condition.

FOWLER.

The village of Fowler is reported to have a public supply, both for fire and domestic purposes, obtained from a drilled well, but no further information was gathered.

EAGLE.

The village of Eagle is also reported to have a partial public supply for domestic use, the water being pumped by windmill from a driven well to a tank.

WATER SUPPLIES OF IONIA COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Ionia County the writer examined each of the several flowing-well districts and visited each town in which a public water supply has been put in operation. But little attention was given to the portions of the county in which flowing wells were not obtained, though it was ascertained that water can generally be had at very moderate depths throughout the county. Indeed, the average depth of the pump wells is less than that of the flowing wells.

Grand River flows through the county in a valley of considerable depth, the bluffs being ordinarily 100 to 150 feet high. The greater part of the upland is a gently undulating till plain, which in places assumes the form of definite morainic ridges of subdued type. There are also narrow strips of gravelly land leading southward between the moraines in the northern part of the county to the valley of Grand River.

FLOWING WELLS AND SPRINGS.

BELDING.

The Belding flows occur only in the city of Belding, along the flood plain of Flat River in Otsico Township (T. 8 N., R. 8 W.), and are distributed over an area of about 1 square mile, as indicated in the sketch map (fig. 36). An understanding of the nature of the flows may best be obtained after an examination of the nature and position of the water-bearing strata. The sections follow:

Record of Richardson silk mill well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Water-bearing sand and gravel with occasional layers of brown clay	35	35
Gravel hardpan	10	45
Blue clay, no stones	55	100
Very fine sand, bearing water with a head of 8½ feet. Material was so fine that it could not be screened and the flow ceased shortly	1	101
Light-colored sticky and stony clay	19	120
Sand, fine but capable of being screened. Present flow from this bed at 120-122 feet	2	122

Record of N. Lapham well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel with streaks of clay	50	50
Sticky blue clay with no stones	50	100
Fine, black, water-bearing sand.		

Record of Belding Brothers & Co. well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Water-bearing sand	25	25
Blue clay without stones	20	45
Quicksand, producing roily water	1	46
Clay	25	71
Coarse water-bearing sand	3	74

Record of Ballou basket works well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Black muck	8	8
Blue sticky clay, no stones	57	65
Fine sand, water-bearing	.5	65.5
Variegated clay	34.5	100
Sand, clay, and stones, with water	40	140
Coarse water-bearing sand.		

The water from the wells of the different companies is used for drinking purposes by the employees. Water for boiler use is drawn out of Flat River. The depths of the different wells, as well as the succession of materials, show the uncertainty of finding water at the particular depth apparently indicated by the conditions in a nearby well. While this is more or less characteristic of water supply in glacial deposits it is more notably the case in the Belding flow than in any others where the wells are as near each other as in this part of the State.

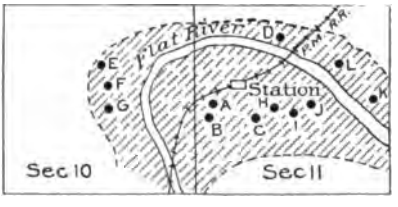


FIG. 36.—Map of Belding flowing-well area. Extent shown by shading.

The flow of water in the second well of Belding Brothers & Co. mentioned in the table below, has decreased from 5½ to 4 gallons a minute. In the well owned by the Ballou basket works the decrease has been from 6 to 1½ gallons a minute. This decrease is due either to the obstruction of the screen by the fine sand in which the water occurs, or to the corrosion of the screen, or to both, this being proved by the condition of different screens pulled up in cleaning wells.

The diameter of the wells mentioned in the table is uniformly 2 inches, and the cost of drilling $2 a foot, including pipe.

The present city supply is from the various city wells or from ordinary dug wells. For fire protection, water is pumped from Flat River and conveyed by a system of wooden mains to every part of the city. The pumping is done for the city under contract by Belding Brothers & Co. The artesian-water resources of the place have encouraged the consideration of plans for the installation of a plant which will furnish water for all purposes.

Wells at Belding (T. 18 N., R. 8 W.).

Letter on fig. 37.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	*° F.*
A	11	Richardson silk mills	1900	121	768	770	1	52.5
B	11	Doctor Little	1904	126	771	774	1	.....
C	11	N. Lapham	1894	100	771	774	6	52.2
D	11	Ballou basket works	1897	140	768	776	1.5	51.9
E	10	N. Lapham	1903	37	678	771	2	50.7
F	10	C. C. Briggs	1892	25	768	771½	8	49.7
G	10	Karl Eckert	1893	35	768	771	Pumped.	50.5
H	11	H. J. Leonard	1890	156	769	773	.75	51.5
I	11	Belding Land and Improvement Co.[a]	1888	300	768	768	Pumped.	.....
J	11	Belding Bros. & Co	1902	131½	770	774	6	52.2
K	11	....do	.....	100½	771	780	4	.....
L	11	Belding Hall Manufacturing Co	1899	155	768	776	1	51.6

[a] At 300 feet "rotten rock" was encountered, the drill broke, and the well was abandoned. A flow was passed at 120 feet. The well at present supplies the Belding Hotel. Flow is 5 gallons a minute 3 feet below surface.

CLARKSVILLE DISTRICT.

The flows of the Clarksville area in the southwestern part of Ionia County occur in and beyond the northern and western limits of the village, which is located on a level till plain extending eastward from a moraine lying a mile to the west. Extremely slight trenching of this plain by Coldwater Creek and its tributaries has occurred, and it is on the shallow valley floors or in natural depressions of the plain that flows are found.

An examination of the accompanying table shows an increase of head in the general direction of the moraine on the southwest. The dug-well records near the southern limit of flow uniformly show the same condition, besides indicating that here, as in the flowing-well area, when the water-bearing stratum is tapped, the water rises with strong artesian effect, until it reaches the approximate level of the static head within the area of flow. This, together with the fact that the flowing wells are shallow and their depths uniform, points to a continuous water bed locally supplied, and attributes to the moraine west of the village the function of a catchment area.

Fig. 37 expresses these and other interesting relations. The lo hill seems to divide the flows, and to constrict them between i southern limit and the higher ground t the south. Beyond the constriction the spread out again, fan-like, and may b found all the way between this point an the creek. These relations, considere with the topography, suggest that in th same way flows may be obtained on th western side of the hill between the rail road track and the creek. The extrem eastern limits of the area may also b extended a short distance, but the ex treme western limits have been well de fined by borings. The head and flow Mr. Merrill's well on the southwester limits of the area indicate a probab extension of the area as indicated in fig. 37.

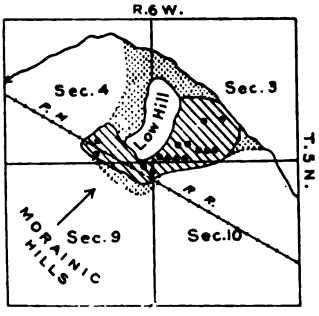


FIG. 37.—Location of Clarksville flows. Present extent shown by diagonal lines; probable extension by dotted lines. Arrow points in direction of underground flow.

The water is in every case hard, and leaves an incrustation of lim stained by iron on the pipe. It is used for stock and domestic pu poses. The largest flow is that of the Merrill well (see table); tl flows in the other wells, except the Hull well, are small. Mr. Hu furnished the following record of materials penetrated:

Record of Hull well, Clarksville.

	Thickness.	Total
	Feet.	*Feet.*
Clayey soil	2	
Solid blue clay	18	
Clean quartz gravel, water bearing.		

The records of other wells show the same succession of materi with remarkable uniformity in the thickness of the clay and the pos tion of the water bed.

Wells in Clarksville district (T. 5 N.; R. 8 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	T P t
			Feet.	*Feet.*	*Feet.*	*Galls.*	
3	G. Ferney		27	815	819	1.33	
3	Dr. A. G. Bush	1894	27	819	819	.5	
3	L. A. Scoville	1894	27	820	822	1	
3	J. Hull	1896	22	820	824	10	
3	G. Ferney		27	820	824	1	
3	E. D. Troyer		27	824	826	8	
3	James Snyder			824	826	1	
3	Eliz. Stewart		25	822	824	.75	
3	F. E. Richards			822	825		
3	M. J. Badder		27	824	825	.14	
3	Wesleyan Methodist Church		25	825	826.5		
3	Fred Hess			827	826		
9	F. W. Merrill		20	826	832	15	
9	do			826	832.5	5	
4	L. Braendle	1894	23	828	830		
4	do	1894	25	826		.12	

HUBBARDSTON DISTRICT.

There are but 2 flowing wells in the village of Hubbardston; one is owned by the village, and the other by C. K. Bennett.

The village well was drilled in 1894 by private individuals to supply a village watering place, and to throw light on the geologic formations present. The depth of the well is 265 feet; diameter, 5 inches; flow, 64 gallons a minute; temperature, 50.8 °F.; altitude, 670 feet; head, 20 feet; cost, $2 per foot. The driller was L. J. Lincoln, of Mason, Mich. John A. Tabor, postmaster at Hubbardston and one of the promoters of the well, kindly furnished the approximate section which follows:

Record of village flowing well, Hubbardston.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel underlain by a few feet of hard blue clay	50	50
Water-bearing sand	55	105
Very hard clay with occasional layers of soft clay	103	208
Thin layers of water-bearing red sand with a flow of 20 to 30 barrels a day	2	210
"Sandy hardpan" with no water	40	250
Sand and gravel from which present flow is obtained	2	252
Sandy hardpan in which drilling was stopped	13	265

The water contains considerable iron and occasionally roils slightly. No reason for this is assigned except that after having been driven to 265 feet the well was dynamited at 250 feet to break the pipe where a flow was known to occur.

The depth of the Bennett well is 50 feet; diameter, 2 inches; altitude, 652 feet; head, 12 feet; temperature, 51.3 °F.; flow, 8 gallons a minute. This well is at present used to supply a sawmill. At one time the citizens of the village undertook to found a sanitarium to make use of the well, but the project was abandoned. The water is said to be derived from gravel beneath a clay hardpan.

In sec. 21, Bloomer Township, Montcalm County, 5 miles northwest of Hubbardston, an old well is reported which was drilled in search of coal. No data are at hand further than the authenticated statement that the well is at least 200 feet deep and flowed when first put down.

Between this flow and the one at Hubbardston there is lower ground drained by a tributary of Maple River. This suggests that the field might be greatly enlarged. The depth is somewhat unfavorable, however, considering the fact that an abundant supply of surface water can be so easily obtained in the ordinary dug wells. Yet for some of the larger farms of this district flows even at the greater depth would be profitable.

Three miles southwest of Hubbardston, on the farm of A. S. Jessup, in sec. 23, T. 8 N., R. 5 W., is a spring yielding 2 barrels a minute, the largest spring found in this part of the State. Tw

years ago its flow was concentrated on the river bluff 50 feet above Maple River, but since then it has cut a gully 250 feet long and 20 feet deep at the mouth. The gully heads in a kettle hole toward which both the surface and the subsurface drainage is directed. The temperature of the water at the head of the gully is 53°, at the mouth 56°. The gully is cut in a marl deposit of considerable thickness, formerly used in the manufacture of lime. Lack of railroad transportation stopped the industry, and no use is now made of the deposit.

IONIA DISTRICT.

General statement.—About 50 feet above the floor of the Grand River Valley are the numerous surface springs of Ionia. Their issuance so high up on the valley side is caused in most places by the outcrop of the clay of morainic origin underneath the sand and gravel in which the surface water accumulates. The water furnished by the springs is used for drinking and household purposes by private families and is the principal source of the supply at the municipal pumping station, the Michigan Reformatory, and the hospital for the criminally insane. The surface water is usually centralized at the mouths of the small valleys tributary to Grand River Valley or in the adjacent kettle holes, which have been tapped through the headward growth of the tributary gullies. A very good example of the latter kind of centralization of drainage is found just back of the river bluffs one-half mile west of Ionia.

John Flater, living just outside of the western city limits, has for years irrigated his garden from a stone reservoir built about 60 feet above the floor of Grand Valley and in the path of the surface drainage. More recently he has irrigated from flowing wells.

Wells.—The following table gives data of flowing wells in the Ionia district:

Wells in Ionia district.

Letter on fig. 38.	Township N.	Range W.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.
						Feet.	*Feet.*	*Feet.*	*Galls.*
E	7	6	27	J. Horrocks	1900	340	694	715	36
D	7	6	21	Prospecting Company		540	665	725	300
H	7	6	30	H. H. Pierce	1901		640	670	1
N	7	6	21	G. W. & H. B. Webber	1896	247	678	700	4
M	7	6	20	Wm. O'Brien	1901	[a] 107	635	637	.25
I	7	6	19	H. R. Welker	1898	340	682	696	30
A	7	6	19	Ionia Water Company	1887	525 650	685		
O	7	6	19	Ionia Gas and Coke Company	1897	190	650	695	.5
B	7	6	19	County of Ionia		320	665	693	1.5
B	7	7	24	W. Yoemans	1899	240	700	720	
A	7	7	24	John Flater		228	650	700	10
C	7	6	19	Township of Ionia	1900	80	642	672	18
L	7	6	20	F. A. Shattuck	1904	67	635	637	.5
J	7	6	20	Harper Brothers	1900	77½	635	640	1
K	7	6	20	H. A. Leek	1903	83	635	643	4

[a] There is some doubt as to the depth of this well. It probably belongs to the 80-foot series.

The data in the above table show, besides the surface system just discussed, two distinct sources of water, one occurring at 80 to 100 feet in gravel underlying blue clay, and the other in rock at depths ranging from 200 to nearly 700 feet.

The wells of the first class yield a large supply of water, although strongly chalybeate in most cases, and might profitably be prospected by the city with a view to future increase of municipal supply. All of the wells drawing water from this stratum, except that belonging to Ionia Township, are in a group on the north side of Grand River Valley; the township well is located almost due south of the above group on the south side of the valley.

The deeper wells draw their supply from the rock. The well of the Prospecting Company has a larger flow than any other named in the table, penetrating so far into a rock formation known to yield water at various depths that it undoubtedly draws its supply from several horizons. The flow was originally a 6-inch stream under a 60-foot head, but through neglect the pipe has become partly filled with

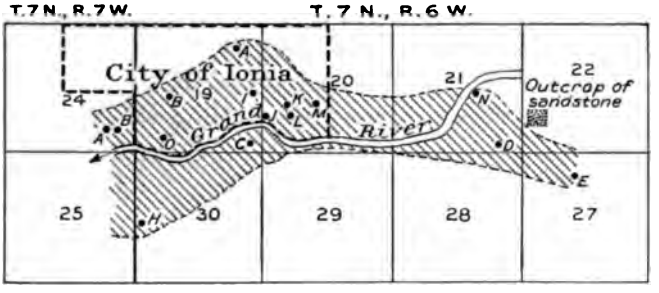


FIG. 38.—Area in and near Ionia in which flows are found. This could be extended some distance both up and down Grand River Valley.

quicksand from the surface, and the flow, while still stronger than that of any other well in this vicinity, is considerably less than at first. The hole was drilled by a prospecting company in search of coal, and on being abandoned by the company the water was piped up the adjacent bluff to a farmhouse and for years supplied the farm. Later its use in this way was discontinued by the breaking of the pipe, and at present no use is made of the water, which is allowed to run into Grand River.

The well records in the table are arranged in three series, approximately in the order of their occurrence down the valley: First, those deep wells which are located on the south side of Grand River; second, the deep wells on the north side; and third, the 80-foot wells on both sides.

The extent of the area under consideration is about 6 square miles but it could be much increased (fig. 38). A flow has been obtained

in Grand River Valley at the village of Saranac and others at Lowell, and there is apparently no reason why flows may not be obtained in the valley in the whole intervening distance between Lowell and Ionia. Up the valley from Ionia as far as Lyons the number of flowing wells, at least at present, seems to depend to a large degree on the number of people who have been able to bear the expense of putting down wells of sufficient depth.

In comparing depths of wells it must be remembered that some are on the valley floor and others on the terraces and valley sides. This accounts for the considerable difference shown in the column of altitudes. No permanent loss of head is noted except in the case of Mr. Yeomans's well, in which the water stands several feet below the surface. This well was dynamited during the drilling, and the consequent filling may have caused the loss of head. Temporary losses are frequent through sand-choked conditions, which could be obviated were the same care exercised in entering the pipe in the rock which drillers in oil regions are forced to exercise. All the deep wells originally supplied from 15 to 75 gallons a minute, depending uniformly on the different depths and the difference between the surface elevation and the head.

The following section of the strata as they occur on the south side of the river was kindly furnished by J. Horrocks, formerly a well driller of Ionia:

Record of well south of Grand River, near Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Drift, sand, gravel, and clay	50	50
Variegated sandstone	70	120
A long series of nonwater-bearing shales and slates, with thin interbedded layers of conglomerate and fire clay, with coal near the top and fire clay and slightly thicker seams of coal at the bottom. The maximum thickness of the coal layers is said to be 3½ feet at 245 feet	170	290
Parma sandstone.		

The Parma sandstone yields water from the top, but the flow increases with the depth. Other sections are as follows:

Record of well of Ionia Gas and Coke Company, Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Black muck	12	12
Soft marl clay	8	20
Coarse white gravel	20	40
Series of shales, with thin coal seams	150	190
Parma sandstone, very much creviced and full of cavities.		

Record of John Flater well (near valley bottom), Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
ter-bearing gravel and sand	90	90
ndstone	110	200
rma sandstone	28	228

Flow began as soon as this sandstone was encountered and increased ith the depth, a fact reported in all wells in this formation.

Record of H. R. Welker well (on terrace), Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
and, gravel, clay, stones, etc	257	257
Fire clay, no grit or sand	3	260
Sandstone, very "soft" for the first 8 feet	43	303
Parma sandstone, very "soft," i. e., loose textured and easy to drill	23	326
Grit, extremely hard, no water	14	340

The supply is obtained in the Welker well from the Parma sandstone. Dynamiting is said to have increased the flow by half.

The 80-foot series of wells all show approximately the following:

Record of 80-foot wells, Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Surface loam	4	4
Blue clay	76	80
Clean, loose, water-bearing gravel.		

The Ionia Water Company, Charles Girard, superintendent, operates four wells supplied from the springs described on p. 240. It also owns four artesian wells varying in depth from 525 to 650 feet. The two deepest ones yielded brackish water, and were plugged. The water in the others is not considered so good as that from the surface wells, and is not used except in cases of emergency. The storage reservoir has a capacity of 13,000 barrels, and holds at all times 5,000 barrels for fire protection. About 800,000 gallons are used daily. The two pumps have a united daily capacity of 3,000,000 gallons.

The following partial analysis shows the composition of water from a deep well owned by H. R. Welker, at Ionia, in the Parma sandstone. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Ionia.

	Parts p
Color	
Iron (Fe)	
Chlorine (Cl)	
Carbon dioxide (CO_2)	
Sulphur trioxide (SO_3)	
Hardness (as $CaCO_3$)	

S. J. Lewis, analyst. Depth, 336 feet.

SHILOH AREA.

But one flow has been secured in Shiloh, Ionia County. located on the farm of C. H. Brown, 1 mile west of Shiloh sta sec. 11 in the valley of a small unnamed tributary of Di Creek. The altitude is 670 feet, the depth 24 feet, and the di 1½ inches.

The well was driven in 1904, the material being sand for t 6 feet and then clay until water-bearing sand was encountere feet. The head is 3 inches, but in lower places in the same many flows could probably be secured with a head of sever The flow at the surface is one-fourth gallon a minute. Th is strongly chalybeate, and the screens are clogged and r worthless after only a few months' use.

WATERWORKS.

LAKE ODESSA.

The pumping station which supplies water to this vil southern Ionia County is on the shore of Lake Jourdan, wh southeast of the village. The lake is in a basin surrounded b or less steep slopes leading up to the gently undulating area o the village is built. The altitude of the lake is 810 feet; tha village 840 to 865 feet or more.

Water is supplied from four 6-inch wells from 48 to 52 fee the water standing 3 feet above the lake surface or 813 feet

owners use. The present system amply supplies the needs of the village. It was established in 1899. The superintendent is Emerson Pool.

MUIR AND LYONS.

Muir and Lyons, neighboring villages in eastern Ionia County, are situated, the one on Maple River just before it joins the Grand and the other on Grand River where it turns sharply to the west. Below this point the river follows an old line of glacial drainage. The villages are built partly on the slopes and partly on the floor of Grand River Valley.

The water supply at both places is from dug wells 20 to 40 feet deep, the water level being about 12 feet below the surface of the flood plain, on which the business parts of the towns are built. In Muir a public drinking fountain is supplied with water from a spring 20 feet above it on the neighboring bluff to the northwest. The water runs by gravity pressure at the rate of 12 gallons a minute. The village has a population of 750, and has no fire protection.

Lyons, with a population of about 880, has a system of fire protection with direct pressure. The pump is operated by waterpower in connection with a gristmill, and is set in motion in a very few minutes. A maximum pressure of 250 pounds may be attained. The pipes extend only along the main street, but are 1,000 feet in length, and give protection to practically all the village on the east side of Grand River. The extension of the mains to the west side of the river is under consideration.

PORTLAND.

The village of Portland, at the junction of Grand and Lookingglass rivers, in Ionia County, has its water supply from 1 well 32 feet deep, dug in 1889, into the bottom of which 18 feet of pipe has been driven, and from five tubular wells driven in 1900 to a depth of 38 to 43 feet. The wells are at an altitude of 727 feet, and are located on the edge of a terrace bordering the flood plain of Lookingglass River. The water rises within 2 feet of the surface under normal static conditions, but the drafted head is much less. When pumped at the rate of 40,000 gallons an hour, the wells show a lowering of head within one-half hour. A steady drafted head is maintained when the wells are pumped at the rate of 15,000 gallons an hour. The water is pumped into a stone tower, 65 feet above the level of the well heads, which has a capacity of 85,000 gallons. To insure a supply of water under high pressure in case of fire, connection is maintained with the river, and river water may be pumped into the mains.

The town is growing steadily, and the mains are being extended so rapidly that new sources of supply must be sought. No deep borings have been made, and in the absence of these tests possible deeper supplies may be neglected. Springs along Lookingglass River, one-half mile above the town, are looked to by the townspeople for increasing the supply.

The superintendent of the waterworks is Charles Selleck. The original cost of the plant was $13,000, and the approximate amount pumped daily is 250,000 gallons.

The following analysis of Portland water was made in 1899 by Prof. R. C. Kedzie:

Analysis of water at Portland.[a]

	Parts per million.		Parts per million.
Total solids	357.15	Temporary hardness	57.15
Volatile at red heat (organic)	42.86	Nitrites	None.
Mineral matter	314.29	Nitrates	21.43
Chlorine	30.00	Free ammonia	.11
Total hardness by soap test	185.72	Albuminoid ammonia	.05
Permanent hardness	128.57		

Water colorless, odorless, tasteless. Quality good. Relatively large amount of nitrates. Hardness relatively high. Organic matter, containing nitrogen, is nearly oxidized. Small amount of chlorides tends to show the water free from sewage. If the water is boiled it is not so hard, some of the $CaCO_3$ being precipitated by boiling.

WATER SUPPLIES OF MONTCALM COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Montcalm County the writer examined each of the several small flowing-well districts, and also each village and city in which public supplies have been established. The county as a whole is well watered, and, aside from flowing wells and a few deep test borings for coal, the residents have sunk few wells to depths of over 50 feet, and many of the wells are 30 feet or less in depth.

FLOWING WELLS.

CEDAR LAKE.

The basin-like area in which the Cedar Lake flows are obtained is at the head of a tributary of Pine River and is partly encircled by sandy hills, the rainfall of which feeds the flows (see sketch map, fig. 39). The best records of materials penetrated in driving the wells are uncertain, but all agree in recording a thin clay layer about 25 feet below the surface, beneath which the artesian supply is obtained. The wells are all about 30 feet deep.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The area has been well developed in its upper part but not in t lower or northern and northwestern part, where more flows c undoubtedly be obtained. The latter section is uncleared and marshy and therefore uninhabited, so that the full extent of the area of possible flows is not determined.

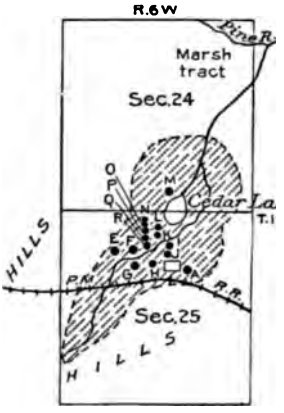


FIG. 39.—Relation of Cedar Lake fl to topography and drainage.

The diameter of pipe used in nearly all cases is 1½ inches. The water of all the wells is strongly chalybeate. The wells are lettered on the map in the order of their occurrence from south to north over an area 100 rods long and 20 rods wide. The first flowing wells were driven about twenty years ago and the others soon after, except the last one in the table, which was put down in 1900 and yields an excellent flow. The rusting of the pipes and clogging by sand makes the other flows irregular at the prese time.

Wells at Cedar Lake (T. 12 N., R. 6 W.)

Letter on fig. 39.	Section.	Owner.	Elevation.	Water rises to—	Flow per minute.	Temperature
			Feet.	*Feet.*	*Gallons.*	°F
A	25	Pere Marquette Railroad	864	867	0.75	
I	25	I. N. Collins	864	870	1.25	
J	25	do	866	867	.25	
R	25	D. E. Cole	859	867	3	
E	25	A. Munn	866	867	.12	
L	25	A. D. Jobes	864	871	.25	
F	25	Fred Brink	862	865	.5	
H	25	Wm. Nelson	864	865½	.25	.....
K	25	Village of Cedar Lake	859	865	1	
Q	25	H. M. Devereaux	859	865	1	
P	25	Sidney Phippeny	864	868	3	
O	25	A. Pierce	864	867	4	
N	25	W. W. Carroll	864	871	.25	
M	24	Sidney Phippeny	854	868	20	

CRYSTAL LAKE DISTRICT.

Under Crystal Lake are treated four isolated and apparent unrelated flows in eastern Montcalm County, lying in a line runni from the west end of Crystal Lake south to the Pere Marquet Railroad.

Near the west end of Crystal Lake in sec. 7, T. 10 N., R. 5 W., is t well belonging to school district No. 7, Crystal Township. It is inches in diameter, 100 feet deep, and barely flows at the surfa which is 777 feet above tide To facilitate getting water a pu has been installed. Attempts to obtain flows on the slightly higl ground elsewhere in the vicinity have been unsuccessful. On t

shore of the lake flows may be obtainable, but no attempt has been made to secure them. The rapid growth of the little summer colony at the eastern end of the lake suggests that such a well might be profitable to the owner. Ordinary dug-well records show the material in which the water occurs to be a rather fine sand underlying clay with alternating layers of quicksand. At the surface is 16 feet of ordinary coarse sand.

The other three flowing wells of the area are extremely shallow, one being 12 feet and two 16 feet in depth. In all three the material penetrated is nearly the same—a few feet of clayey soil, then clay or quicksand to the bottom, where coarse water-bearing gravel is encountered. The wells are all on low ground near brook courses and seem, so far as suggested by the topography, to depend on a very limited catchment area for their supply. The water is strongly impregnated with iron, and the flow, on account of the coating formed on the screen, soon decreases and finally ceases altogether. The pipe is then driven down a few inches with a stone or sledge hammer, which loosens the deposit around the screen and thus restores free circulation, so that the original flow is resumed. On account of the slight depth the total cost of each well was but a few dollars.

Wells in Crystal Lake district.

Township N.	Range W.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
9	6	12	F. B. Lovett	1900	16	777	779	1	51.5
9	5	6	M. A. De Hart	1889	16	784	787	.12	.....
10	5	30	M. S. Gambee	1896	12	804	806	1	52.2

There are many springs in this locality, all yielding iron-impregnated water. The flows in the shallow wells apparently have a source identical with that of the springs. The fine quicksand, even where clay is altogether lacking, offers sufficient resistance to the upward passage of water to permit the maintenance of a low head in the underlying stratum.

WHITE FISH LAKE.

The single flowing well of C. C. Hartt at White Fish Lake in western Montcalm County (T. 11 N., R. 10 W., sec. 20-A) is of unusual interest in suggesting the possibility of obtaining artesian water in similar localities elsewhere on the shores of the larger morainic lakes, where flows are not usually expected. Steep morainic hills inclose White Fish Lake and ordinary dug-well records show the gradient of the clay and sand layers beneath the surface to be steep also. This, with the particular alternation of material found here, as shown in the carefully kept record below given by Mr. Hartt, favors the possibility of flows:

Record of Hartt well, White Fish Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Fine, yellow, water-bearing sand	40	40
(This yields a flow at 30 feet, but the material can not be screened.)		
Blue clay, free from stones and sand	30	70
Clay and gravel mixed, running into clean water-bearing gravel	5	75

The well was driven by the owner in 1899. The temperature is 50.2°. The flow is so strong, because of the 20-foot head, that a screen is unnecessary. The 2-inch stream yields about 40 gallons a minute and supplies a small summer village of about 20 families, which have been attracted to the lake partly because of the excellent water. Enough iron, sulphur, and sulphureted hydrogen is contained in the water to make it medicinally valuable, a feature in greater or smaller degree present in most flowing wells in this part of the State. The above constituents were determined through a partial analysis made by Professor Kedzie in 1899.

WATERWORKS.

CARSON CITY.

Carson City is located in the southeastern part of Montcalm County, on the western border of the Riverdale moraine. The district is drained by Fish Creek, a tributary of Maple River. The population of 890 get their water supply from dug and driven wells 12 to 60 feet deep in gravel lying beneath clay. The average depth of the wells in the village is 24 feet, the average distance to water being 20 feet. A village water system was established in 1888 at a cost of $13,000, which supplies water for manufacturing purposes and fire protection at the rate of 20,000 barrels daily. The water is pumped from Fish Creek and conveyed along the principal streets in 6-inch and 8-inch mains which have a total length of 10,824 feet.

EDMORE.

The Edmore water system was installed in 1880 and uses four 2½-inch driven wells each 60 feet deep. The depth to water is 40 feet and the surface elevation 944 feet. Pumping is not continuous, the pumps being run only four hours daily. The water is pumped into a reservoir with a capacity of 2,600 barrels, which stands sufficiently high above the village to give strong pressure. The system is chiefly for fire protection, the water being used by only about 60 families, and by these chiefly for toilet purposes. The water mains are located only on main streets and have a total length of 2,260 feet, half being of 6-inch and half of 3-inch pipe. The water is very

hard, and continuous use of a borax compound is apparently the way to preserve the boilers from scaling.

The above data were furnished by H. T. Aldrich, engine Edmore pumping station.

The dug wells, which supply the greater part of the village w are from 16 to 40 feet deep in sand and gravel, and as the frequently in close proximity to cesspools they are a menace t health of the village, a feature of water supply by no means cor to Edmore. There are no flowing wells in the village.

GREENVILLE.

Greenville, in southeastern Montcalm County, gets its supply wells in the valley of Flat River, the pumping station being sit on the flood plain west of the Pere Marquette Railroad bridge. altitude of the surface at this point is about 800 feet.

There is one open brick well, 24 feet in diameter and 20 feet connected with nine 6-inch wells 40 feet deep. The water, wl from the same bed in all the wells, stands from 3 to 5 feet belo surface. The material in which the water occurs is sand and g which extends 40 feet below the surface—the depth of the tu wells. The water bed is limited below by a layer of stony clay

The present system was established in 1888. Its original cos about $44,000, but the extensions and improvements made since will increase this amount to a total of $70,000. The Holly d pressure system is in use, pumping on an average for the year 30 gallons daily. At present between 400 and 500 families us public water. Water is delivered and fire protection secured th nearly 10 miles of mains.

With a view to an increased flow of water to the pumps and fore ease of pumping, a deeper 4-inch boring was put down in 50 feet south of the pumping station, at a cost of $300, by H Gardner, of Birmingham, under the direction of Mr. William S. ard, superintendent of the Greenville water system. Mr. R Motlet, engineer at the pumping station, furnished the foll record:

Record of deep boring at waterworks, Greenville.

	Thickness.
	Feet.
White, water-bearing sand	42
"Hardpan," hard, stony clay	2
Water-bearing sand and gravel	10
Hard, dry, stony clay	45
Alternating layers of dry clay and water-bearing gravel, terminated by coarse sand and gravel containing water with greater head than any previously encountered	67

The water rises to 820 feet above tide, or 20 feet above surfac and the flow is 20 gallons a minute. A high percentage of sulphu reted hydrogen and iron gives the water an extremely unpleasar odor and taste, so that it is not used for public supply. Except fc its limited use medicinally it is allowed to run to waste into Fla River from the jet fountain which it operates.

The position of the waterworks with reference to adjacent slope and shallow drainage has been well chosen, but the water is all surfac water and contamination from near-by sources is not impossibl Danger would be lessened if the wells were driven 5 feet deeper, to th water-bed beneath the hard, stony clay.

HOWARD CITY.

The flows at Howard City occur near Tamarack Creek, and, as th table shows, they have such a small head that but a short distanc back from the creek they can not be obtained.

Flowing wells in Howard City (T. 12 N., R. 10 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
23	Howard City	1903	151	867	874	20	49
23	B. J. Lowrey	1898	136	870	874	2	.....
23	C. C. Messenger	1900	47	871	873	.5	.....

The city well mentioned in the table is only 3 feet above the surfac of Tamarack Creek. In driving it two water-bearing strata wer encountered—one at 47 and one at 80 feet, with the same head the the deeper one exhibits. The ground water is within 7 feet of th surface throughout the area back from the immediate neighborhoo of the creek. The surface sand is 35 feet thick and is underlain b several feet of hard blue clay. The first flow is found under the clay i a gravel layer about 4 feet thick. Blue clay extends below this to th bottom of the well, except for the layer of gravel, bearing artesia water at 80 feet. No further attempts to obtain flows are known t have been made near by along Tamarack Creek. Attempts hav been made several miles upstream, but because of insufficient hea have not succeeded.

The pumping station at Howard City was established in 1890 an furnishes creek water for fire protection and toilet purposes onl The mains are 4, 6, and 8 inches in diameter. On an average 200,0 gallons are pumped daily. The capacity of the pumps is 1,500,0 gallons a day. The engineer is R. A. Smith. The city drinkin water is obtained in part from the flowing well at the pumping statio the water being carried in buckets, and in part from ordinary du wells, which have an average depth of about 35 feet.

STANTON.

The water supply of Stanton, the county seat of Montcalm County, is obtained from two wells dug to a depth of 20 feet, into the bottom of which 10-foot lengths of pipe are driven. Under pumping the water is 1 foot below the surface; the static head is 2 feet above the surface. The water is pumped into two basins—one is built of cement and has a capacity of 90,000 gallons, the other is formed by a wooden curb resting on clay and has a capacity of 7,000 gallons. The daily amount supplied to the village is about 150,000 gallons. The plant was established in 1890 at a cost of about $13,000. Since 1896 an electric lighting plant has been operated in connection with the waterworks.

The character of the Stanton water may be better understood from the succession of deposits found here. The surface sand and gravel continue down, becoming increasingly finer to from 20 to 25 feet below the surface, where clay is found having a thickness of about 20 feet in some places 50 feet. Water-bearing gravel and sand lie beneath the clay and it is chiefly from this source that the village is supplied. The water is artesian and of the quality indicated by the following analysis made by Prof. R. C. Kedzie in 1885:

Analysis of water from Stanton artesian well.[a]

	Parts per million.
Total solids	296.01
Volatile at red heat (organic)	38
Fixed mineral residue	258.01
Calcium (Ca)	68.36
Magnesium (Mg)	23.05
Sodium (Na)	.79
Chlorine (Cl)	1.21
Sulphate radicle (SO_4)	.71
Carbonate radicle (CO_3)	158.89
Silica (SiO_2)	5
	258.01

The volatile matter consists chiefly of organized carbon and contains no organic nitrogen (yielding albuminoid ammonia). It contains a slight trace of free ammonia—0.01 per million parts of water. It contains traces of nitrates but no nitrites. In a sanitary view this water is good, with the exception that it is hard.

About 25 rods north of the village wells and close to the west side of the railroad track is the well of O. D. Vandebogtt, which is 30 to 35 feet deep and penetrates similar material, the clay bed being

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

hinner at this point. An analysis of the water made in 1886 gave he following results:

Analysis of water from Vandebogtt well.[a]

	Parts per million.
'otal solids	279.10
'olatile at red heat	40
Fixed mineral reside	239.10
'alcium (Ca)	67.58
Magnesium (Mg)	17.29
Sodium (Na)	.79
Chlorine (Cl)	1.21
Sulphate radicle (SO_4)	.29
Carbonate radicle (CO_3)	142.93
Iron (Fe)	Trace.
Silica (SiO_2)	9
	239.09

The temperature of the water is 49.2° F.; altitude, 870 feet; head, 2 feet; flow, 2 gallons per minute; diameter of pipe, 2 inches; driller, James David.

The surface water in the vicinity of Stanton continues to the clay layer, and has a variable head, directly related to local rainfall.

From the fact that the curb well at the pumping station rests on the clay and that the lowering of the head by pumping prevents the artesian water from counteracting the inflow of the surface water, it will be seen that more or less surface water enters the wells. There is thus a source of contamination, rendered the more easily possible from the fact that the pumping station lies below the village in direct line with the surface drainage, and the danger is augmented by the lack of a sewer system.

About the village are numerous springs, differing greatly in mineral properties. Some contain large quantities of lime, others iron, and still others sulphur and magnesia in quantities sufficient to be decidedly laxative in effect. The springs are at the foot of gravel hills and express the concentration of surface waters at gradients too steep to enable the water table to adjust itself quickly enough for a continuance of subsurface flow.

Aside from the small area of low ground adjacent to the pumping station, there seems to be no opportunity for the further development of artesian wells in this section.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

WATER SUPPLIES OF OTTAWA COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

This county, which borders Lake Michigan and was largely covered by the lake after the withdrawal of the ice sheet, has wide areas of sand in which surface wells are obtained at depths of 20 feet or less. Below the sand there is usually a compact clay into which wells may need to penetrate to considerable depths before striking the water-bearing sand and gravel. As yet the deeper water beds have been explored but little. The flowing-well districts lie in the eastern and southern parts of the county, and are associated with morainic ridges which serve as catchment areas, as indicated below. The writer gave attention chiefly to the flowing wells and public supplies of the several towns, and gave only casual attention to other supplies.

FLOWING WELLS.

CONKLIN DISTRICT.

The flows of the Conklin area (see fig. 40) occur near the headwaters of a southeastern tributary of Crockery Creek in the northeastern part of Ottawa County. This tributary drains the intermorainic area just east of that described in the Coopersville report, but the stream flows north and around the Coopersville area and reaches Grand River southwest of Coopersville. The flows have been developed at only a few places in the broad sag between the moraines, and their possible extension is unknown. The topography of this area is more irregular than that of the intermorainic area west of it, and consequently the flows are not in such close relation as those at Coopersville.

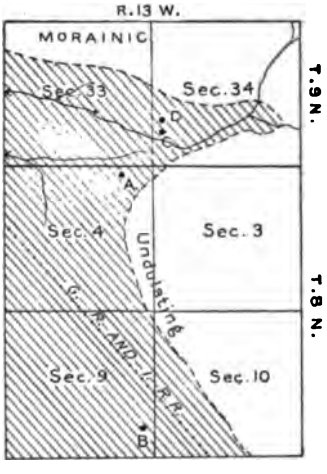


Fig. 40.—Possible extent of Conklin field over sections where flowing wells occur.

Originally the greatest flow was from the well of Mr. John Zimmer, which yielded 20 gallons a minute when first drilled and had a head of 30 feet. Through deposition on the screen the flow has diminished to one half gallon a minute. The other wells have suffered similar but not so great decrease.

Wells in Conklin area (Tps. 8 and 9 N., R. 13 W.).

n.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
4	J. Zimmer	1890.	50	842	872	0.5	52.5
9	A. Mapes	.....	170	790	.....	.12	53
34	S. W. Wright	.....	.....	832	834	.75	51.9
34	.....Do	.....	.....	853	854	.75	51.2

COOPERSVILLE AREAS.

oopersville flows occur in two areas near the village, in north-Ottawa County, each about 200 acres in extent, and on low adjoining Deer Creek. (See fig. 41.) The creek drains a ntly rolling, narrow, intermorainic plain, extending roughly rth-south direction and terminated on the south by Grand alley. The influence of the deep River Valley in lowering the water the higher contiguous areas is felt stance up each of the streams. re to be expected, therefore, not mouths of short tributary streams Deer Creek, but some distance he mouth and nearer the source tream, the precise location within ts thus defined being determined relief.

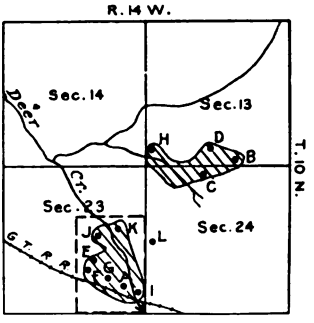


FIG. 41.—Coopersville flowing wells. Village is inclosed by broken line; flowing-well areas are shaded.

ntire catchment basin and valley Creek occupy only about 30 square The moderate depth of the wells ir steady increase of head toward the northeast indicate that surface direction of artesian-water movement is from the lying east of the creek. A small catchment area for flows y results in seasonal fluctuations in the strength of the flow, bably all the wells in this area have such fluctuation, though ew observers have noted the fact. Mr. Henry Jackson says s well flows one-fourth stronger in winter than in summer, " here including much of the spring and autumn. Mr. Jack- nishes the following record of material penetrated:

Record of Jackson well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
.....	8	8
.....	6	14
.....	20	34
lternating layers of sand containing considerable iron and "lignite".	66	100
ring sand, becoming coarser with increasing depth	36	136
ring gravel.		

This water rises to within 15 feet of the surface. The deeper supply failed at the end of six months and the well was dynamited at 100 feet; the pipe was broken and the present flow resulted.

Other sections are as follows:

Record of Heinz pickle factory well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	80	80
Quicksand, water bearing and becoming slightly coarser with increasing depth	29	109

Record of C. P. Lillie well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	8	8
Clay with occasional layers of sand, some of which are water bearing	142	150
Fine water-bearing sand, becoming coarser with increasing depth	10	160
Water-bearing gravel.		

The cost of drilling this last well was $1 per foot.

The Osiah Noble well penetrated clay 112 feet to a bed of water gravel, but ceased to flow one hour after the village well (see table) began to flow. They are but a few hundred feet apart. The flows in a number of wells decreased when the village well was made, in some instances causing serious inconvenience to the owners, as in the case of Alex. Noble and the Heinz Pickle Company. The water from the village wells has until recently been allowed to run to waste. There has been a marked decrease in flow in all the wells of the area as the number of wells has increased, and it will be necessary to enforce the State law against waste of artesian water if this district is to receive the maximum of benefit from its artesian waters.

The two flowing-well areas are apparently not parts of the same field or pool, for efforts to secure flows along the creek or the higher ground between them have been unsuccessful. The approximate limits of each area have been defined by borings.

The water everywhere is chalybeate and hard, leaving an incrustation with strong iron stain on the pipes. This condition tends to corrode the screens and decrease the flow, in addition to the cause of decrease noted above. The lack of screens in many of the wells tends toward the same result. Repeated sand pumping and the insertion of new screens have been temporary remedies.

Wells at Coopersville (T. 8 N., R. 14 W.).

ter fig.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	*° F.*
A	23	Village of Coopersville	1903	92	622	646	3	51.9
B	13	L. Terry	1904	182	658	690	3	51.2
C	24	S. Fynewever		160	658	659	.12	
D	13	H. Jackson	1895	100	668	683	.05	
E	23	C. P. Lillie	1904	166	640	644	1	
F	25	Mr. Parker		335	642	645		
G	23	Heinz pickle factory		109	637	650	.06	
H	13	Peck Brothers	1899	203	644	644		
I	23	O. Noble	1898	113	640	646	4	
J	23	Alex. Noble	1892	94	638	641	.1	
K	23	Miss Hamilton			648	650		
L	24	Henry Lake	1903	204	658	656		

DRENTHE AREA.

The first three flows in the table below have hydrographic relations somewhat different from those of the rest of the flows in this section, and are therefore discussed separately. They occur on Drenthe Creek at the border between the moraine and the till plain, which extends south and southwest from the central part of Zeeland Township into Fillmore Township, Allegan County. They belong to that class of flows which have their catchment area in a moraine, and are made possible by the erosion, in this case slight, which the streams have effected, this erosion having worn down the surface to a level lower than that to which artesian water will rise. East of the flows the moraine offers, by its gentle slopes and in places sandy nature, a good opportunity for the imbibition of the rain water that supplies the wells.

Ter Haar reports clay in his well for the first 85 feet followed by water-bearing gravel. The following section for C. Verhulst's well is similar:

Record of C. Verhulst well, Drenthe.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	90	90
Hardpan	2	92
Soft clay or quicksand	5	97
Water-bearing gravel	11	108

All other wells in this vicinity are from 90 to 100 feet deep, but being on slightly higher ground, do not flow. In many cases the water-bearing material, which is often a fine sand, can not be screened well enough to allow pumping directly from the pipe. The owners have adjusted their methods to meet this condition and built reservoirs 10 to 15 feet deep, into the bottoms of which pipes are driven down to the water bed. The bottoms of the reservoirs are below the

head of the water, which thus flows into the reservoir. This arrangement gives a greater supply of water in case of fire than would otherwise be possible.

The flow in all the wells has decreased, a condition attributed by the owners to the clogging of the pipes and the rusting of the screens. The water is hard and contains a great deal of iron.

Relations of flows and relief similar to those at Drenthe may be found along the other streams south of Drenthe at points where a line drawn from Drenthe to Overisel intersects the drainage lines.

Wells near Drenthe (T. 5 N., R. 14 W.).

Letter on fig. 42.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
A	27	Drenthe Canning Co.	1889	100	642	644	1	52.2
B	27	Ter Haar	1889	93	.....	.....	2.5	.....
C	27	C. Verhulst	1897	108	632	.....	1	51.9

BEAR CREEK AREA.

One mile south of Forest Grove, in southeastern Ottawa County, is another group of flows in the valley of the northernmost tributary of Bear Creek. Their occurrence within the moraine noted above and not on plains at the border of moraines is unique. They are

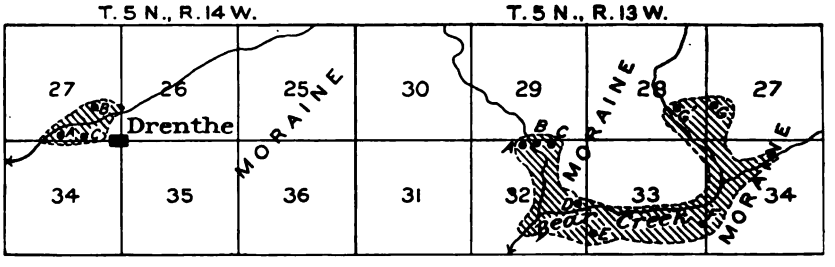


FIG. 42.—Map of Bear Creek and Drenthe flowing-well districts.

found in a basin shaped by the ice, whose slopes are sufficiently long and steep to favor the development of artesian flows. The sections are not unlike those at Drenthe, given above, and the water is strongly chalybeate.

Record of Edward Kropschot well, Bear Creek Valley.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	30	3[illegible]
Hardpan	1	3[illegible]
Sand, too fine to permit flow	39	7[illegible]
Gravel	3	7[illegible]

Record of Albert Karsten well, Bear Creek Valley.

	Thickness.	Total.
	Feet.	*Feet.*
.....	35	35
bearing sand.....	2	37

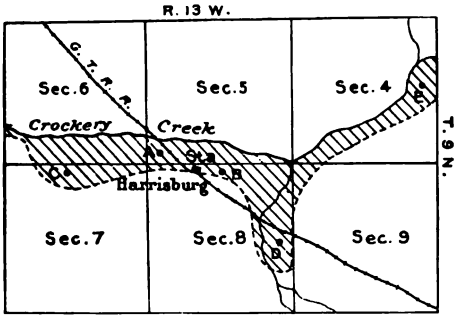
rface water in pockets of sand in the clay supplies wells where ; can not be obtained. The extent of this flowing-well area has been determined because of the small number of borings. How- it is unlikely that it will be extended much farther.

Wells near Bear Creek (T. 5 N., R. 13 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
29	Ed. Kropschot.....	1901	73	648	660	0.2	52.2
32	H. Strick.....	.....	15	658	659	.5	.....
32	B. Schreur.....	1902	26	645	660	12.5	52
32	Thos. Palmbus.....	1904	37	635	637	.12	53
33	A. Karsten.....	1903	37	650	652	.25	51.1
33	George Nash.....	.....	27	655	660	.16	52.5
27	K. Closter.....	1903	38	653	661	2.5	52

HARRISBURG AREA.

e flows at Harrisburg occur in an area of 1 or 2 square miles it along the southern and eastern side of the main branch of kery Creek (fig. 43). They are obtained only on this side of the , and show increase of head toward the east in the direction of



.—Location of flowing wells at Harrisburg, Ottawa County. Area of probable flows is shaded.

noraine, which bounds them on that side. They occur on a flat ey plain, through which Crockery Creek flows rather sluggishly. water of the whole area is strongly chalybeate. The material untered here is shown by the record furnished by Mr. Gilbert.

Record of Gilbert well, Harrisburg.

	Thickness.	Total.
	Feet.	*Feet.*
Clay, no stones, occasional pockets of water-bearing sand, which supply dug wells of the area	28	28
Coarse water-bearing gravel. Flow begins directly beneath clay, but being at first from somewhat finer material increases with depth	42	70
Peat.		

The flowing well on the Sherk estate is described as having a peculiar origin. A dug well furnished water for the farm until about seven years ago, when a break occurred in the clay bottom and the present flow began. The same conditions are reported in a few other places in the State.

The area has been tested well enough for the determination of the limits of flow, but many more flows could be obtained within those limits. The water is used for general farm purposes, and much of it allowed to run to waste.

Wells at Harrisburg (T. 9 N., R. 13 W.).

Letter on fig. 43.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
A	5	A. Bodell	1897	72	695	700	1.5	50.0
B	8	W. H. Harrison	1894	90	707	711	1.5	50.5
C	7	Wm. De Valve	1897	60	655	661	2	50.5
D	8	Jos. Gilbert	1884	42	702	714	6	54.2
E	4	Sherk estate	1884	22	718	720	4	51.2

WATERWORKS.

GRAND HAVEN.

Two separate water plants supply Grand Haven with water, one being owned and operated by the city and the other by a private company. The latter, called the Grand Haven Water Company, is the outgrowth of an earlier organization, which was established in 1884 as an independent company. The Grand Haven Water Company pumping station is in the eastern part of the city; the municipal plant is in the western part; both are on the banks of Grand River.

The city also has sunk a deep boring for the purpose of obtaining artesian water. The following record of the strata found was furnished by Dr. A. C. Lane:

Record of Grand Haven artesian well.

	Thickness.	Total.
	Feet.	*Feet.*
.....	25	25
avel.....	15	40
clay.....	6	46
mixed with gravel and sand.....	24	70
e clay.....	95	165
low clay mixed with gravel and sand.....	16	181
e clay.....	16	197
istone.....	6	203
.....	5	208
ale with occasional very thin layers of limestone.....	278	486
estone.....	1	487
le with thin limestone layers.....	35	522
ale with thin limestone layers.....	24	546
e limestone.....	8	552
l limestone, water very salty.....	6	558
y sandstone.....	8	566
l limestone mixed, water very salty and increasing.....	22	588
ted.....	12	600

72 driven wells of the Grand Haven Water Company are 5 in diameter and about 28 feet deep. There are also two open 12 feet in diameter and 28 feet deep. The normal level of is 12 feet below the surface and the pumped level 15 feet below. levation of the surface above the river is 24 feet, or 605 feet sea level, and the distance from the river is 500 feet. The -pressure system of pumping is used. The mains have diam- of 12 to 6 inches and a total length of 8½ miles. About 375,000 s are supplied daily, the capacity of the pumps being 1,500,000 s. The material penetrated in putting down the wells is as s, the supply being from the gravel above the clay:

Record of Water Company wells, Grand Haven.

	Thickness.	Total.
	Feet.	*Feet.*
sand becoming coarser with increasing depth.....	24	24
earing gravel.....	4	28
, no stones.		

city pumping station is in part supplied with water from one d dug well 24 feet deep and 30 feet in diameter, in which the stands about 12 feet below the surface. Its natural level is 11 to 15 inches above the river, which is about 75 feet away. naterial is fine dune sand at the surface, changing rapidly to sand and then to fine gravel. Three feet below the bottom well, or 27 feet below the surface, is a very obstinate layer of pan, which appears in the bed of Grand River and renders g or spile driving difficult. The spiles used have to be tipped steel, as those solely of wood are splintered when driven down e hardpan. The water comes into the dug well from the land and not from the river side.

The other wells are tubular—45 are 4-inch and 8 are 8-inch. The water level and the material are the same as in the dug well.

The wells are all arranged parallel with the river bank and extend over a distance of 250 to 300 yards. The direct-pressure system is in use. On an average for the year 750,000 gallons are pumped daily, the capacity of the pumps being 1,500,000 gallons. The elevation of the wells is about 10 feet above the level of Lake Michigan, or 591 feet above tide. The mains are 12, 10, 8, 6, and 4 inches in diameter.

The two following analyses show the character of the water supplied from the city pumping station:

Analysis of water from Grand Haven waterworks.

	Parts per million.
Total solids	148
Volatile solids	40
Fixed solids	108
Nitrogen as free ammonia	None.
Nitrogen as albuminoid ammonia	.04
Nitrogen as nitrites	None.
Nitrogen as nitrates	3.20
Chlorine in chlorides	17

Turbidity, none. Sediment, slight. Color, faint opalescent. Odor, none. A pure and wholesome water, free from all objectionable elements and suspicious bacteria. J. N. Hurty, Indianapolis, analyst, November 19, 1898.

Doctor Hurty says further:

The water contains iron, and in the warm summer months certain minute vegetable growths which are perfectly harmless get started in the water. They flourish in the bends and dead ends or other quiet places in the pipes, and when considerable in amount break loose and are drawn out in the faucets. These plants have a great liking for iron and have the power to extract it from water. They are so very small that in the aggregate they appear like slime, and when mixed with iron the mass is not inviting. The musty odor is imparted by the plants just as an onion odor would be imparted by onions or a turnip odor by turnips. The name of the plant in your sample is *Crenothrix Kuhniana*. It is as harmless as turnip, but is objectionable on account of the musty odor which it imparts and which is characteristic of the plant. The plant might be gotten rid of by aeration and filtration. Aeration would probably precipitate the iron, and if it did filtration through sand would remove the iron so precipitated. Whether aeration would precipitate the iron or not, would have to be determined by experiment.

Analysis of water from Grand Haven waterworks.[a]

	Parts per million.
Total solids	150
Volatile at red heat (organic)	48.57
Mineral residue after ignition	101.43
Calcium (Ca)	32.03
Sodium (Na)	4.61
Magnesium (Mg)	2.79

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

	Parts per million.
Carbonate radicle (CO_3)	54.89
Chlorine (Cl)	7.10
Ammonia (free)	.05
Albuminoid ammonia	.03

Colorless, tasteless, odorless. Bacteriological tests show absence of disease germs. Quality excellent for potable use. R. C. Kedzie, of the Michigan Agricultural College, analyst, October 8, 1898.

COOPERSVILLE.

The village pumping station is a few feet above the flood plain of Deer Creek, 15 or 20 feet below the even till plain on which the village stands and in which the creek is incised. The present system, including the wells, pumps, reservoir, and 2.6 miles of mains, was installed in 1903, at a cost of $14,000. The pumps have 12 feet of suction and a capacity of 30,000 gallons.

Up to the autumn of 1904 creek water was pumped through the mains, giving fire protection to the whole village, besides furnishing 55 families with water for washing and toilet purposes; but in the spring of 1904 two 90-foot artesian wells were installed, yielding a flowing pressure of 40 pounds to the square inch at the surface, and their water was substituted for that of the creek. A cement brick reservoir, 20 feet in diameter and 20 feet deep, with the top at the level of the well head, is being built. Into this the water is to flow, and is then to be pumped into the stand tower to run by gravity into the mains. The substitution of potable for creek water is expected to increase the number of consuming families to about 150. Superintendent Horling gives the following careful record of material penetrated. Other data may be found in the table of wells.

Record of village well at Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and peat	10	10
Micaceous quicksand	2	12
Blue clay	10	22
Quicksand	2	24
Conglomerate ("hardpan")	4	28
Coarse, water-bearing sand	6	34
Blue clay with occasional layers of sand	50	84
Fine water-bearing sand, bearing a high percentage of muscovite-mica scales	12	92

HOLLAND.

The city of Holland, with a population in 1900 of 7,790, is located in the southwest corner of Ottawa County at the head of Black Lake, 5 miles from the shore of Lake Michigan. The sandy plain on which it is built is terminated on the east and south by a moraine, and on the west is surmounted by several long lines of sand dunes

actively growing near the lake shore, but inactive farther inland Penetrating to the border of the rich and extensive farming regioı which centers in Holland, the long and narrow Black Lake is navi gable for all lake craft and gives Holland commercial advantages surpassed by but few lake ports.

The public water supply is derived from wells at two different stations, one on Nineteenth street, the other on Fifth street. The water is raised by electrically driven triplex pumps, motive power being supplied by an electric-light plant owned and operated by the city. This plant is located on Fifth street not far from the head of Black Lake. Near it are 4 open dug wells 25 feet deep and having about 20 feet of water. At the Nineteenth street pumping station are 6 tubular wells 25 feet deep, siphoning into an open brick and cement well 40 feet in diameter and 29 feet deep, to which they are located radially. Three of the wells are 5 inches and three are 4½ inches in diameter. The siphon lines are 8 inches in diameter and are started by suction from the pumps. During the year ending March 21, 1904, the total amount pumped from the main station on Fifth street was 98,500,000 gallons, and from the Nineteenth street station over 104,500,000, making a total of over 203,000,000 gallons. The average amount pumped daily was 557,000 gallons, which is nearly 70 gallons daily per capita. The total number of taps installed is 1,095, of which 1,032 are in active service. Of the water meters in service 818 are ⅝-inch, 16 are ¾-inch, 9 are 1-inch, 4 are 4½-inch, 4 are 3-inch, 2 are 2-inch, and 1 is 4-inch, making a total of 854. There are 108,809 feet, or about 21 miles, of water mains, ranging from 14-inch down to 2-inch, about half being 6-inch. The standpipe is 18 feet in diameter and 130 feet high and has a capacity of 247,000 gallons. The total cost of operating during 1903, including salaries of employees, fuel, repairs, anc sundries, was $7,780. The total cost to date is $134,000 and th estimated present value is $118,000.

The yearly increase in the consumption of water is large, and thei has been apprehension lest in the dry summer months, when th head of water falls off 7 or 8 feet, there might be a serious shortag in the supply.

In the attempt to secure deeper sources a tubular well was sun to a depth of 111 feet in 1903 at the Nineteenth street pumpin station, and water found which rose 5 feet above the surface. Th superintendent, Mr. James De Young, estimated that with a 20-foc screen 50,000 gallons could be drawn from this well daily. Unfoı tunately, the water is strongly saline and unsuitable for publi supply.

The following record of material penetrated is supplied by Mr. e Young:

Record of flowing well at waterworks, Holland.

	Thickness.	Total.
	Feet.	*Feet.*
Medium beach sand	29	29
Blue clay without stones, but gravelly for the first 3 feet	60	89
Stony clay	22	111
Very sharp gravel, water bearing, mixed with silt.		

In the southern part of the city is the flowing well of Benjamin Walter, over 100 feet deep, on ground slightly higher than Nineteenth street, and also yielding saline waters. The flow from this well is one-eighth gallon a minute, the temperature 53° F., and the head 8 or 9 feet. It was drilled by Edward Riemink in 1896, the same succession of material being encountered as in the Nineteenth street well.

It appears, in view of the foregoing, that unless a suitable supply of water is found at greater depths than these saline flowing wells, or is obtained from remote sources, the shallow-well system will have to be extended. Southeast of Nineteenth street station is an open tract of land available to the city. If this is purchased and kept clear of dwellings, it may yield a pure supply sufficient for some years. Eventually the city may find it necessary to draw its supply from Lake Michigan, which, fortunately, is near enough to be reached without great expense.

The following partial analysis of the public water supply at Holland has been furnished by M. O. Leighton, of the United States Geological Survey. The supply is from about ten wells sunk to an average depth of 30 feet.

Partial analysis of well water at Holland.

	Parts per million.
Color	19
Iron (Fe)	Trace.
Chlorine (Cl)	1.5
Carbon dioxide (CO_2)	58.04
Sulphur trioxide (SO_3)	25
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 30 feet.

ZEELAND.

The village of Zeeland is in southeastern Ottawa County, about 12 miles from the shore of Lake Michigan. The Zeeland Light and Water Company's present system was established in 1902 at a cost of $20,000, not including the cost of the mains. About 225,000

gallons of water a day are supplied to about 100 families besides six different factories and mills.

The water is obtained from two brick-curb wells 20 feet deep and 14 feet in diameter, which were dug in 1890. The level of the water is 8 feet below the surface, and is not affected by pumping 2,000 gallons a minute. The capacity of the two compound duplex pumps in use is 1,500,000 gallons a day. The direct-pressure system is used.

There are 3½ miles of mains with a diameter of 6 inches, but these will soon be replaced by 8-inch mains, being inadequate to supply the growing demand for water. There is at present no map of the mains.

The wells are located off the main street in Zeeland. Near them are the cesspools and privies common to smaller villages. The supply of water is wholly from the surface and would seem to be particularly liable to contamination, though the surface is quite flat and subsurface drainage is slow. The present system has been in use only two years, and the increased pumping seems likely to drain a larger and larger area around the wells, and so increase the danger of pollution. No chemical or hygienic analysis of the water has been made, so far as known. The water should be subjected to frequent analysis, and deeper sources of supply should be sought and substituted.

MISCELLANEOUS ANALYSES OF WELL WATERS.

By Isaiah Bowman.

Analyses of water from wells in Clinton, Ottawa, Ionia, Montcalm, and Newaygo counties.

[Parts per million.]

Township N.	Range W.	Section.	Quarter.	Town or district.	Well.	Owner.	Hardness.	Chlorine.	Alkalinity.
7	2	12	SE.	Ovid	Public	Municipal	130.9	2.500	150
9	2	27	SW.	Eureka district	Flowing	W. C. Baylis	154.7	.816	7
8	3	3	NW.	Essex township	do	Z. Wyman	178.5	.170	6
7	3	3	NE.	St. Johns district	do	G. Feightung	226.1	.067	125
8	14	24	NW.	Coopersville district	do	S. Tynewever	107.1	.600	66
9	13	7	NW.	Harrisburg district	do	W. DeValve	83.3	.301	50
5	14	27	SE.	Drenthe district	do	Drenthe Canning Co.	178.5	.300	53.5
11	11	31	SE.	Ensley district	do	School district No. 9.	77.35	.335	120
5	8	3	SW.	Clarkville district	do	Parsonage	95.2	.248	77
9	8	9	SE.	Greenville	do	Municipal	71.4	.335	127.5
8	8	11	NW.	Belding	do	H. Leonard	107.1	.167	110
12	10	26	SE.	Howard City	do	Municipal	142.8	.330	105
12	6	21	SW.	Edmore	do	do	47.6	.300	150

Isaiah Bowman, analyst.

WATER SUPPLIES OF KENT COUNTY.

By JOHN F. NELLIST.

DRAINAGE AND WATER POWER.

The surface water supply of Kent County embraces four rivers and their small affluents, numerous springs, and an extensive artesian district which gets its supply from the Marshall sandstone. Strong wells are obtained in drift, some of those in the valleys being artesian.

Grand River, the main stream of the county, enters the county on the east side and flows for 37 miles across it, making a long bend to the north and returning to the west side on its way to the lake. This river has within the county a fall of less than a foot to the mile except at the rapids in the city of Grand Rapids, where it falls about 17 feet over limestone ledges in less than one-half mile. A dam was placed at the head of the rapids about 1836, and canals dug on both sides of the river to supply mills. A town, which grew up around these mills, has developed into the flourishing city of Grand Rapids with 100,000 inhabitants and a world-famous furniture industry, the result of its water power and timber resources. The river has a valley about 150 feet deep cut by a stream flowing from the receding ice sheet. The width is over a mile, and the valley is marked by terraces and islands.

The minimum flow in the last three years, since the gage station was established at Grand Rapids, was 1,885 second-feet; the maximum flow during the extreme flood of March 24–30, 1904, was 39,400 second-feet. This flood was 19.30 feet above low-water mark, the danger line being at 10.73 feet, as determined by Fred Schneider, section director of United States Weather Bureau.

The tributaries of Grand River in Kent County are Flat, Thornapple, and Rouge rivers. Flat River, emptying into it from the north at Lowell, is a stream of remarkable steadiness of flow due to its many lake tributaries and porous soil. It has a drainage area of 610 square miles and a minimum flow of 215 second-feet, as measured by R. J. M. Danley in September, 1899, and by the writer in September, 1904. Its rapid fall of some 8 feet to the mile has been extensively used for power, four plants being located in Kent County. The Lowell dam is used for local mills. The two plants of the Grand Rapids Edison Company of 300 and 1,000 horsepower, respectively, transmit power to Grand Rapids by high-power electric transmission. Still farther up the valley is the old Fallasburg dam not now in use.

Thornapple River has a drainage of 824 square miles and a minimum flow of 155 second-feet, as measured by L. W. Anderson in September, 1899. The small minimum flow per square mile (less than half that of Flat River) is due to the rapid run-off in the wet

season, there being few lake basins to act as reservoirs and much impervious clay soil. It has several power plants, one owned by Wesley N. Hyde, of Grand Rapids, being located at Labarge, and supplying electric power to neighboring villages; another at Alaska is used to run a sawmill; another, purchased by Grand Rapids parties, is at Cascade, where they propose to build a 20-foot dam; and another at Ada is used to drive a gristmill. The average fall is about 4 feet to the mile.

River Rouge has a drainage area of 230 square miles and a minimum flow of 110 second-feet, as measured by Otto Krause, September, 1902 and 1904. Two power plants are located on this stream one at Rockford supplying current for lighting the village, pumping its water, and running a shoe factory and another at Childsdale used to run a paper mill. The fall of this river is only a few inches to the mile except in the last 6 miles of its course. It has the largest flow in proportion to its drainage basin of any river in Kent County.

WATERWORKS.

GRAND RAPIDS.

The chief water supply of Grand Rapids for domestic and various other purposes is obtained from Grand River. It is pumped to a low-service reservoir one-half mile east of the river on a bluff 177 feet above city datum and to a high-service standpipe located at the same place at an elevation of 256 feet. A new standpipe of concrete is being erected in the southern part of the city at an elevation of 206 feet to supply that district. The city had, in 1904, a daily consumption of 14,000,000 gallons. The pumps consist of one Holly of 10,000,000 gallons capacity for the low service and a Norburg engine of 15,000,000 gallons capacity for the high service. Two old Butterworth and Lowe engines are kept in reserve, but are not in regular use There are 152 miles of mains in use, as follows:

Water mains at Grand Rapids.

Diameter in inches.	Length in miles.	Diameter in inches.	Length in miles.
36	0.019	12	14.723
24	1.600	10	7.045
20	1.853	8	19.811
18	.749	6	56.754
16	6.088	4	40.556
14	.230		

The total cost of the water works up to April 30, 1904, was $1,505,521. The income for the year 1904 was $127,897.

A small supply of water has been furnished to the northeastern part of Grand Rapids by a private concern known as the Hydraul

ompany, which must soon go out of business, as its charter was epealed by the State legislature in 1905. This company has a few niles of pipe and a pumping station one-half mile north of the city imits, which draws from a well on the bank of the river.

On account of the large number of cases of typhoid fever in the city ach year, there has arisen a prejudice against the present supply rom Grand River. Several new sources have been suggested, among hich three are prominent: Bailey Springs, supplemented by filter eds for Grand River; Flat River, and Lake Michigan.

Bailey Springs is situated 3 miles north of the city and has a ground-ater drainage area of some 14 square miles, nearly all the water of hich can be intercepted by a conduit 4,000 feet long laid along the ast bank of the river below the level of the river bed. It is estiated that a supply of from 7,000,000 to 10,000,000 gallons a day an be thus collected. With sand filters at Grand River for the dditional supply a sufficient amount of pure water could be obtained. he cost of establishing this system is estimated at $700,000.

A gravity system from Flat River can be obtained by going 35 niles northeast of the city, where the water is 330 feet above city latum. The plans embrace building a concrete conduit of 12 miles rom the source to Silver and Bostwick lakes, which are 265 feet above ity datum and which have storage capacity for one hundred days consumption, or 2,500,000,000 gallons. From these storage reservoirs to Grand Rapids steel pipe could be used and connected to the present system at a net head 10 feet above the present system.

A plan to draw from Lake Michigan has been proposed by A. C. Sekell, of Grand Rapids. It calls for (1) a pipe line 27 miles long, leading directly west from the city; (2) a storage reservoir about 1 mile from the city limits on the west bluff of Grand River; (3) a 4-foot steel-riveted pipe laid to the pumping station on the shore of the lake where collecting mains would be distributed parallel with the lake shore and wells sunk in batteries below the level of the lake bottom, so that the ground water would be intercepted. This system, with gas producers and gas-engine pumping units, could be built for $1,100,000, and would have a capacity of 35,000,000 gallons a day.

Engineers Hazen and Gray were employed in 1899 to make a report on additional water supply for the city, and, after a thorough survey of all the sources, recommended the placing of sand filters about 2 miles above the present station, at a cost of $1,062,000, to supply the immediate needs of the city and the adding of filters as they should be required.

MICHIGAN SOLDIERS' HOME.

The Soldiers' Home is located near the northern limits of Gran Rapids. Maj. E. B. Taylor, adjutant at the home, reports as follow concerning the water supplies and equipment in March, 1906:

You are informed that this home has a waterworks system of its own entirely indepen ent of any municipal system. The supply is from three sources: First, from three spring which are used by this home for drinking and cooking purposes; second, from what known as "Soft Water Lake," the water from which is used for the boilers; third, fro a pond made by damming Lamberton Creek, the water from which is used for sprinkli purposes and fire protection. Our pumping plant consists of one pump of a capacity 15,000 gallons, one of 20,000 gallons, one of 30,000 gallons, and one fire pump of 500,0 gallons per day. From 700 to 1,250 persons are supplied, according to the membersl of this home at various times of the year.

ROCKFORD.

Rockford, situated on the banks of River Rouge, has a municip water system consisting of a tank of 3,000 gallons capacity, situat on a hill west of the village. The distributing system consists 1,350 feet of 8-inch, 2,310 feet of 6-inch, 6,270 feet of 4-inch, ar 1,000 feet of 2-inch, mains. Cast-iron pipes are laid in the princip streets. The pumps and pipe are owned by the village, and tl pumps are operated by electric-motor current furnished under co tract by Hirth, Krause & Co. The daily consumption is 216,0 gallons. An ordinary pressure of 60 pounds and a fire pressure 100 pounds is carried. The plant cost $11,200.

SPARTA.

Sparta is supplied by a system owned by the Welch Folding Be Company, which consists of a tank of 3,000 gallons capacity and cast-iron pipe distributing system of 1,200 feet of 7-inch, 1,880 fe of 6-inch, and 5,280 feet of 4-inch, mains. The supply is obtaine from Sparta Creek, and a fire pressure of 75 pounds is carried.

LOWELL.

The village of Lowell is supplied with water by a system consis ing of 20 2-inch wells pumped to a reservoir of 3,000 gallons capacit which stands on a hill east of the village. The distributing syste consists of 9,240 feet of 8-inch, 9,200 feet of 6-inch, 7,020 feet 4-inch, 2,310 feet of 2½-inch, and 1,450 feet of 1-inch, mains. Tl 2½- and 1-inch pipes are of wrought iron; the others are cast iro The system is owned and operated by the Grand Rapids Edis Company, and was built by A. C. Sekell in 1893.

FLOWING WELLS.

There are several flowing-well districts obtaining supplies fro the drift and one obtaining them from the rock. The writer invest gated the rock district and five of those which obtain supplies fro the drift, and Mr. Bowman the two others (pp. 274–276).

CANNON TOWNSHIP.

Near the point where Bear Creek opens into Grand River Valley in Cannon Township (T. 8 N., R. 10 W.) a single flowing well has been obtained in the NW. ¼, sec. 29. It is at an altitude of 700 feet, or about 80 feet above the river, but the bordering uplands rise above 900 feet. The well is 150 feet deep, mainly through bowlder clay. It has been running about ten years and has nearly stopped flowing. Probably a narrow strip along Bear Creek Valley and the neighboring part of Grand River Valley would yield flows, but no tests have as yet been made.

ADA TOWNSHIP.

In a recess on the east side of Grand River Valley in sec. 9, Ada Township (T. 7 N., R. 10 W.), are 2 flowing wells with a surface altitude of 720 feet, or about 100 feet above the river. They are each 84 feet deep, mainly through clay, and are about exhausted. It seems probable that flows may be obtained in the neighboring low bottoms of Grand River Valley, and perhaps this district is connected with the Cannon district.

SPARTA.

At Sparta village, in T. 9 N., R. 12 W., several wells formerly flowed, but have now entirely stopped, apparently because of exhaustion of the field. The wells were all very shallow, and the general lowering of the ground-water level may account for their cessation.

PARIS TOWNSHIP.

In an abandoned valley forming a line of glacial drainage in the western part of Paris Township (T. 6 N., R. 11 W.) are 2 wells located in NW. ¼ sec. 29 that are only 13 feet deep. They are at an altitude of 680 feet and the water rises just even with the surface. The material is blue clay down to a water-bearing gravel overlying the limestone. The water is rather soft and is bottled and sold in Grand Rapids for drinking purposes under the name of "Ponce de Leon water." It has been used commercially since 1848. An analysis by John De Boe follows:

Analysis of Ponce de Leon water.

	Parts per million.
Calcium carbonate	123.12
Calcium sulphate	Trace.
Sodium chloride	Trace.
Organic matter	30
Total solids	153.564
Nitrites	None.
Nitrates	.422
Free ammonia	.015
Albuminoid ammonia	.022

Total hardness, 7.2°.

BELMONT.

At a hotel in Belmont, in T. 8 N., R. 11 W., there is a flowing we 100 feet in depth, with a surface altitude of 660 feet and a flow o 2 gallons a minute. It carries considerable iron. Belmont is si uated in a recess in the north bluff of Grand River near the mouth of River Rouge. It is probable that flows may be obtained el where in this low tract and perhaps for some distance up Rive Rouge Valley.

GRAND RIVER VALLEY DISTRICT.

From the north line of Grand Rapids to a point several miles down the river there are flowing wells penetrating in some cases to the Marshall sandstone and obtaining a flow of water sufficiently fresh to be suitable for drinking. They pass through the salt- and gypsum-bearing beds of the lower Grand Rapids group, which, as indicated below, was at an early date tested for brine. Most of the wells in the northeastern part of Grand Rapids, however, have been abandoned on account of the brine which has permeated from these old salt wells down into the Marshall sandstone. Below the Marshall sandstone the water again becomes more saline. Care must therefore be taken in sinking to case out the upper salt water and to stop drilling before reaching the lower salt water. In this district the surface altitude is within a few feet above or below 600 feet.

The largest well is located in the Hermitage basement, corner of Canal and Bridge streets. It is 8 inches in diameter, 385 feet in depth, and flows at a pressure of about 3 pounds. The temperature of the water is 50° F. At Eagle Hotel a well 209 feet deep has some brine in it. At the Widdicomb Block is a well furnishing the sole water supply for the establishment. At the county jail there has been a flowing well, but no data were obtained as to its present condition. The Leonards refrigerator works at the corner of Market and Railroad streets have two wells, one plugged, the other used for fire protection. The water is unfit for boiler use. The wells are 245 feet deep; one is 5 inches, and the other 7 inches in diameter. In the basement of the Rindge Kalmbach Block, corner of Ionia and Fulton streets, is a flowing well only 33 feet deep with 13 feet of earth and 20 feet of rock. It flows about 1 gallon a minute and is used for drinking purposes. In the basement of the Weatherly & Pulte Block, near the corner of Ionia and Pearl streets, is another flowing well whose water is used for drinking. The Furniture City Brewing Company has a 6-inch well, drilled in 1904, 170 feet deep, in which the water rises to within 5 feet of the surface. At the Grand Rapid gas works and the Wallin tannery are flowing wells. There is als one on a vacant lot at the corner of Shawmut and Gold streets. Th Luce Furniture Company has a well at the factory on Godfrey avenue

he Alabaster Company have three wells at their factories southwest the city. The Pere Marquette Railroad shops have a new 5-inch ll 165 feet deep, flowing 1,500 gallons an hour. At the tollgate forks of road to Grandville is a well flowing a weak stream.

Between the wells just mentioned and Grandville is an interval 2 miles in which no borings have been made, but conditions seem be as favorable for obtaining flowing wells as in neighboring stricts above and below.

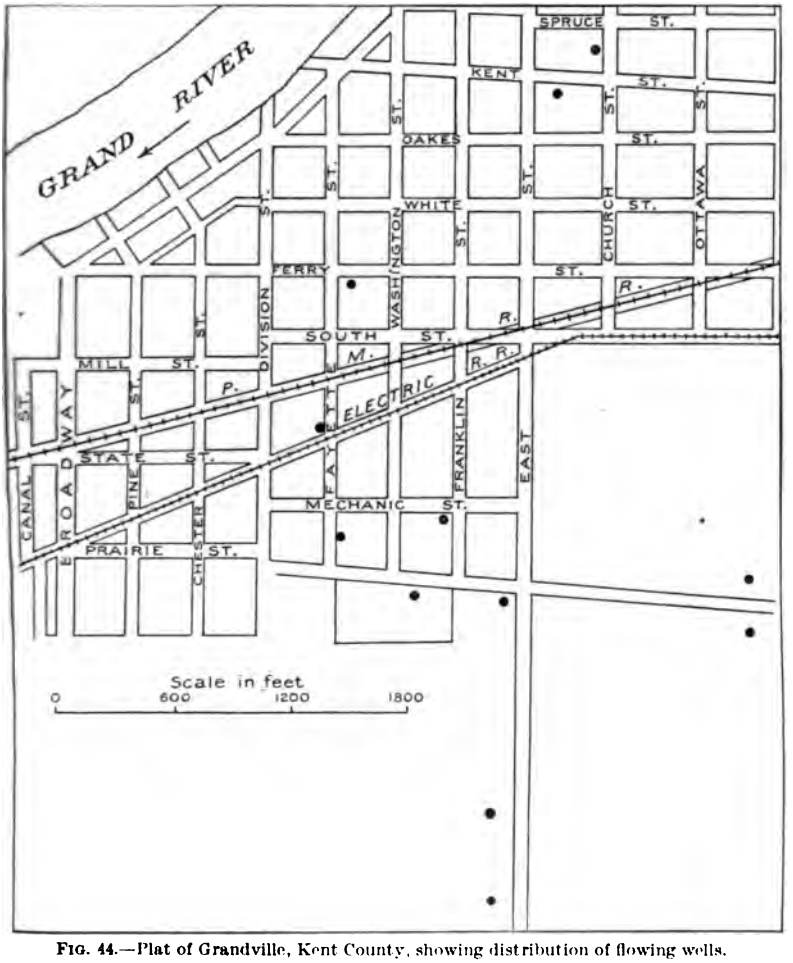


FIG. 44.—Plat of Grandville, Kent County, showing distribution of flowing wells.

Grandville uses no other supply than its flowing wells. There are ten wells within the village limits, two on the Grandville road one-fourth mile east of the village, and two one-half mile south. Some of these wells are 5- and 6-inch, and are capped with fire plugs so that an engine can be attached in case of fire. Small faucets or pet-cocks on the wells flow all the time in cold weather to prevent freezing.

At Jennison, 1 mile west of Grandville, are four wells put dow some fifteen years ago and in good condition to-day. These well were all drilled by O. S. Taylor of Grandville and are from 120 t 170 feet deep. The cost was $2 a foot for 5-inch and $2.50 for 7-inc holes, including pipe.

LOWELL.[a]

The writer examined only two of the flowing-well districts of Ken County, located one on the east and the other on the north borde of the county, and closely connected with adjoining counties whos entire area received attention. Kent County, with the exception o these two flowing-well districts, is reported on by J. F. Nellist.

The village of Lowell stands at the mouth of Flat River, on th north side of Grand River in eastern Kent County, in T. 6 N., R. 9 W., and had a population of 1,776 in 1900. The Grand Rapid Edison Company controls the water system, and data concernin this system appear in the report of Mr. Nellist (p. 267).

The old waterworks system once operated by the village is locate on the flood plain of Grand River at an altitude of 636 feet, at whic elevation the wells were said to flow 1½ feet above the surface. Th material in which the wells were sunk consists wholly of sand, whic is very fine near the surface and offers greater resistance to th upward movement of the water than does an open pipe and thu enables the water to flow.

The most interesting well in Lowell is that of Goodrich Kopf, located in the southern part of town near Flat River. It was drilled in 1887 to a depth of over 100 feet and flowed for six months, when in attempting an alteration of the pipe a break resulted and the flow ceased. Below 20 feet of surface sand there is 80 feet of blue, slightly stony, clay, beneath which is a black water-bearing sand which yielded the flow. The water rose 3 feet above the surface, which has an elevation at that point 10 feet above the old waterworks well, or 646 feet above tide. The water was of good quality, containing a little iron and sulphur, but not in sufficient quantities to affec the taste. It was said to be remarkably clear and pure.

No other well in Lowell seems to have penetrated this blue-cla layer. That it is persistent is shown by the dug-well records collected in all of which, where the depth was sufficient, the clay was found No one besides Mr. Kopf searched for water below it. That it is potable water and that the supply is ample seems fairly indicate by the results which he obtained. Hundreds of acres of land alon Grand River are 10 to 15 feet lower than the surface at Mr. Kopf well, and flows should be obtained over the whole of this area, eve when differences of head are considered, these being generally sma in short distances.

[a] By Isaiah Bowman.

SAND LAKE.[a]

The wells in this area are located near the head of the valley of Black Creek in T. 10 N., R. 10 W., in northern Kent County. Mr. Farnham's well is 1 mile below the source of the creek, which originates in a kettle lakelet on the divide between Rouge and Flat rivers. A half mile farther down the valley is the well belonging to the school district 1 mile east of Sand Lake, and a mile farther down the valley is the well of Mr. Grosvenor.

The following sections show the character of the water-bearing material in this area:

Record of R. Farnham well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Surface soil and muck	4	4
Hard stony clay	11	15
Quicksand, changing gradually to coarse sand	30	45

The material could not be screened until the final depth given was reached.

Record of schoolhouse well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Ordinary surface sand	3	3
Blue clay, dry and tough	27	30
Clean water-bearing gravel	6	36

There is no quicksand between the clay and gravel. Cost of well, $20.

Record of Grosvenor well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Clayey subsoil, becoming sandy with increasing depth	20	20
Blue clay	4	24
Quicksand, becoming coarser until coarse sand and gravel were reached	6	30

These records are typical of all others for this area. The blue clay layer is persistent throughout, and with but two exceptions is underlain by quicksand or very fine water-bearing sand, which is difficult to screen. This condition, combined with peculiar drilling methods and the wishes of well owners, is the reason for some peculiar differences of head and flow and therefore of temperature. In this locality there is a decided preference among well owners for the use of easily operated pitcher pumps in wells instead of allowing the water to flow. The flat surface would allow the waste water to collect in pools in the yard, giving it an unsightly appearance.

[a] By Isaiah Bowman.

Fortunately, the conservation of the water supply is by this mea secured, although it is not a primary consideration in the mind the well owner.

It is said to be difficult to install the pump if there is a strong flow water, and the driller who has driven most of the wells in this locali J. S. Parker, says that for this reason he tries to drive the pipe only far into the fine sand below the clay as will permit merely a slight fl The true head of the water is by this means rendered indetermin except where a flow is secured under more favorable circumstances in the well of Mr. Philo. Here the temperature of the water is lo than elsewhere in the area, a condition in this as in other cases du the strong flow and the consequent slight effect of the relativ warmer pipe in raising the temperature during the ascent of the wa Where the flow is slight the temperature is always modified. The t temperature of the subsurface water therefore is nowhere clos expressed except in the case of strong flows. Compare the temp ture of the Philo well (47.5°) with that of the Reed well (50°).

The Sand Lake flows occur in an area of 5 square miles ext They have in general a low head which could be considerably creased (though the present method of drilling works an advanta yield chalybeate water, whose source is in the moraine and clay p at the head of Black Creek, and belong to that general class of w which obtain water of local origin at slight depth beneath clay. F the head of the water in the well in the series farthest down the va it is clear that if other conditions are favorable more flows could obtained in that locality. The valley some distance below this p is wooded and flat and therefore not settled, which accounts for undeveloped condition of this section of the area with respect to w The cost of installing wells is 50 to 75 cents a foot. The pit pumps in common use cost several dollars. The last two w described in the table are used in supplying the boiler in a sawm The others are for stock and domestic purposes.

Wells at Sand Lake (T. 10 N., R. 10 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Ten at
			Feet.	*Feet.*	*Feet.*	*Gallons.*	
4	R. Farnham	1899	45	885	885½	3	
4	T. J. Blanchard	1892	32	882	883½	.12	
4	C. Cavanaugh	1902	41	897	900	1.5	....
4	School district	1904	36	900	901	Pumped.	....
10	T. J. Blanchard	1902	43	895	897	.12	....
3	.....do	1902	33	899	902	3	
3	D. B. Phillips	1892	33	900	901	Pumped.	....
3	A. Hudson	1892	33	870	874	.5	
3	J. W. Marshall	1890	30	899	901	Pumped.	....
10	Mr. Grosvenor	1900	30?	893	895	.06	
2	L. Reed	1898	30?	887	886	Pumped.	....
2	.....do	1898	30	885	886	....do	....
2	.....do	1898	35	879	883	.5	
1	A. J. Philo	.....	22	867	871	10	
1	.....do	.....	25	870	871	2	....
3	W. Kohn	1894	32	880	881	.....	....

NONFLOWING WELLS.

arge number of the wells obtained from the drift are not flowing ,- and yet yield large amounts of water, there being a general ibution of water-bearing sand and gravel beds in clayey areas as as in sandy areas. On the highest moraines the wells frequently ı a depth of 100 to 200 feet and have but a few feet of water. he more level tracts, especially the broad sandy plains of the ıeastern part of the county, also the terraces along the rivers, ;ells are shallow, ranging from 10 to 50 feet in depth. The wells pland tracts that are not morainic, especially in the portion of ounty south of Grand River, are frequently sunk to depths of 50 ·0 feet. The wells from the rock are confined almost entirely to d River Valley, where flows are often obtained as noted.

SALT WELLS.

veral salt wells were drilled in Grand Rapids about 1860 on side of the river. The range in depth was from 260 to over 500 but the deeper wells passed below the Marshall sandstone and ined no additional flow. Considerable brine was pumped for a , but the wells have all been abandoned. The Taylor well on ıl street in the bed of Cold Brook Creek is still flowing. The rs never had a strong flow, and some barely reached the surface.[a]

SPRINGS.

here are strong springs along Grand River between Grand Rapids Ada, also along Thornapple Valley near Whitneyville and at Cas-. Crystal Springs are in the north bank of Plaster Creek south of nd Rapids, and farther southeast others occur along a depression hich no surface stream is found. Besides these there are numer-weaker springs along nearly every stream in the county, which, as ıole, is exceptionally well supplied with springs, some of which are ady of high commercial value.

rystal Springs, on Madison avenue, 1¼ miles south of the city limits Grand Rapids, on the bank of Plaster Creek, comprise some 60 ngs. The water of the largest is bottled and sold for drinking poses as Crystal Spring water. About 3,000 gallons a day is sold. n the same township, Paris, in the SW. ¼ sec. 8 and the NW. ¼ 9, are two springs known as Pantlands Springs, one used for a pond and stock, the other for a public watering trough and wn as the "watering-trough spring."

'uster Spring on East Bridge street hill in Grand Rapids is used to ply the Grand Rapids Brewing Company and is also bottled and l as Arctic Spring water, the amount sold being perhaps 1,500 gal-s a day.

Vinchell, A., Ann. Rept. Mich. Geol. Survey, 1860; also, Lane, A. C., Geology of Michigan, vol. 5, latter contains the record of a deep boring which extends down into the Devonian limestone.

Harrison Springs, on the Fourth street hill on the west side of Grar River, issue at several places along a small valley. The water is bo tled and sold as Minnehaha water in about the same amount as that Custer Spring.

Mill Creek has two large springs that have been piped down fro the hills west of the village, one supplying the West Michigan Fa Grounds through a 6-inch pipe, and the other supplying the Michiga Black Bass Fish Hatchery at a head of about 24 feet.

Three miles north of the city on the east bank of Grand River ar the extensive Bailey Springs, which have been proposed for a partia water supply for Grand Rapids and a e estimated to yield 7,000,00 gallons a day. These springs apparently embrace in their catchment area a large part of the high tract in the bend of Grand River above Grand Rapids. There is considerable water coming to the surface for a distance of 3 miles along the east bank of the river from sec. 6, Grand Rapids, to sec. 29, Plainfield Township, but the strongest springs are in sec. 29.

At Cascade, on Thornapple River, east of Grand Rapids, are extensive springs used for fish ponds and for a sanitarium. These springs are derived largely from drift deposits; but in the center of the river are others carrying sulphureted waters that may be from gypsum rock. They are used for baths and for medicinal purposes.

The Whitneyville Springs west of the village have not as yet been developed, but are of great strength and of excellent quality.

INDEX.

A. Page.

ron Township (Macomb County), wells in..... 203-204
me Township (Montcalm County), plat of, showing well distribution... 247
wells in..... 246-247
da Township (Kent County), wells in.... 271
dair, water supply of..... 208
Addison, water supply of..... 81
Adrian, waterworks of..... 79
wells at and near..... 78
water of, analysis of..... 79
Adrian Township (Lenawee County), well in..... 98
Agricultural College, wells at..... 175
Aladedon Township (Ingham County), depth to rock in..... 171
Alamo, water supply of..... 130
Albion, waterworks at..... 131, 132, 133
waterworks at, water of, analysis of... 133
Alcona County, rainfall in..... 10
wells in, water of, temperature of.. ... 16
Algonac, waterworks at..... 205, 208
Algonquin, Lake, location of..... 6
Algonquin beach, location of..... 6
Allegan, waterworks at..... 152, 153
Allegan County, flowing wells in..... 153-160
rainfall in..... 10
topography of..... 152
village supplies in..... 153
waterworks in..... 152-153
wells in..... 152-160
records of..... 158-159
temperature of..... 16
water of, analysis of..... 155, 160
Allen Township (Hillsdale County), wells in..... 102
Almont, waterworks at..... 217
Alpena, rainfall at and near..... 11
Alpena County, rainfall in..... 10
wells in, water of, temperature of..... 16
Amboy Township (Hillsdale County), wells in..... 99
Anchorville, wells near..... 204-205
Ann Arbor, springs at..... 16, 140-141
springs at, temperature of..... 17-20
temperature at, variation in, chart showing..... 20
waterworks at..... 22, 142-145
wells at and near..... 138, 140-142
water in, analyses of..... 140, 144
temperature of..... 15, 17-20
variation in, chart showing. 20

Page.

Antrim County, rainfall in..... 10
wells in, water of, temperature of..... 16
Antrim shale, occurrence of..... 73
water from..... 66
Antwerp Township (Van Buren County), wells in..... 123
Arcadia Township, wells in..... 218
Arenac County, rainfall in..... 10
wells in, water of, temperature of..... 16
Arkona, Lake, character and location of... 61
Arkona beach, location of..... 6
Arlington Township (Van Buren County), plat of, showing well distribution..... 124
wells in..... 124-125
Armada, waterworks at..... 199
Armstrong, A. H., information by..... 155
Artesian map of Michigan..... 6
Ash Township (Monroe County), wells in..... 27, 30, 38
Assyria, water supply of..... 163
Athens, water supply of..... 132
Atkins, wells near..... 211
Attica, water supply of..... 217
Attica Township (Lapeer County), wells in. 218
Auburn, depth to rock at..... 177
Augusta, water supply of..... 130
Avoca, water supply of..... 208
Avon Township (Oakland County), wells in..... 189, 195-196

B.

Bailey Springs, location of..... 278
water supply from..... 269
Bainbridge, wells at..... 118
Bainbridge district, plat of, showing well distribution..... 118
wells in..... 117-118
Bainbridge Township (Berrien County), plat of, showing well distribution..... 115, 118
wells in..... 111, 114-115, 117-118
Bancroft, wells in..... 175
Bangor, waterworks at..... 120, 121
Bangor Township (Van Buren County), wells in..... 125
Baroda, water supply of..... 113
Barron Lake, water supply from..... 111
Barry County, flowing wells in..... 163-164
rainfall in..... 10
topography of..... 160
village supplies in..... 163

Page.
Barry County, waterworks in..... 161-162
wells in..... 160-164
temperature of..... 16
water of analysis of..... 162
Batavia, water supply of..... 105
Bath, wells in..... 175
Battle Creek (post-office), waterworks at. 131-132
waterworks at, water of, analysis of... 133
wells at..... 132-133
Battle Creek, drainage of..... 131, 164
wells on..... 132
Bay County, rainfall in..... 10
wells in, water of, temperature of..... 16
Beaches, glacial-lake, locations of..... 6
underground water on..... 7
Bean Creek. *See* Tiffin River.
Bear Creek, wells on..... 258-259
wells on, records of..... 258, 259
Bear Creek area, plat of, showing well distribution..... 258
wells in..... 258-259
Bedford Township (Monroe County), wells in..... 27, 32
Belding, plat of, showing well distribution. 236
wells at..... 235-237
records of..... 235-236
water of, analysis of..... 236
Belford, wells at and near..... 177
Bellaire, wells at..... 8
Belle River, drainage of..... 205, 213
Belmont, wells at..... 272
Belmore beach, location of..... 6, 25
wells of..... 67, 82, 88, 199
Bennington, wells in..... 175
Benton Harbor, waterworks at..... 112, 113
Benton Township (Eaton County), wells in. 175
Benzie County, rainfall in..... 10
wells in, water of temperature of..... 16
Berlin Township (Monroe County), wells in. 27, 30
Berrien County, flowing wells in..... 113-118
location of..... 110
rainfall in..... 10
topography of..... 110
village supplies in..... 113
waterworks in..... 111-113
wells in..... 7, 111-118
water of, temperature of..... 16
Berrien Springs, water supply of..... 113
Berville, water supply of..... 208
Big Meadows area, wells in..... 188
Bingham Township (Clinton County), plat of, showing well distribution... 229
wells in..... 228-229, 230
Birmingham, depth to rock at..... 177, 183
rainfall at..... 49
waterworks at..... 182
water of, analysis of..... 182
Bismarck, wells in..... 169
Bismarck-Roxana district, wells of..... 169
Black Creek, wells on..... 275
Black River, drainage of..... 205
wells on..... 126, 209
Blissfield, wells at and near..... 78, 81
Blissfield Township (Lenawee County), plat of, showing well distribution. 87

Page.
Bloomer Township (Montcalm County), well in..... 239
Bloomfield Township (Oakland County), wells in..... 189
Bloomingdale, plat of, showing well distribution..... 126
water supply of..... 121
wells in..... 125
Bog lime, water from..... 74
Bonsteel flowing well, view of..... 149
Bored wells, description of..... 13
Bowman, Isaiah, analyses by..... 266
on Barry County..... 161-162, 163-164
on Clinton County..... 225-235
on Eaton County..... 164-170
on Graatschap area..... 155
on Ingham County..... 164-170
on Ionia County..... 235-246
on Lowell wells..... 274
on Montcalm County..... 246-253
on Ottawa County..... 254-266
on Sand Lake wells..... 275-276
on Wayland area..... 155-160
work of..... 2, 270
Boyne, wells at..... 8
Branch County, flowing wells in..... 104
location of..... 104
rainfall in..... 10
topography of..... 104
village supplies in..... 105
waterworks in..... 104-106
wells in..... 104-105
water of, analysis of..... 104
temperature of..... 16
Brandon Township (Oakland County), wells of..... 184-187, 188
Bravo, water supply of..... 153
Breedsville, water supply of..... 121
wells at and near..... 125-126
Bridgeman, water supply of..... 113
Brines, salt secured from..... 75
Britton, wells at..... 81, 88
wells at, water from, analyses of..... 88
Bronson, water supply of..... 105
Brooklyn-Clark-Lake-Norvell district, wells of..... 126-127
Brooklyn (Allegan County), water supply of..... 153
Brooklyn (Jackson County), water supply of..... 135
wells near..... 136
Brownstown Township, springs in..... 74
wells in..... 65, 67, 70, 76
water supply in..... 75
Bruce Township (Wayne County), wells in. 201
Buchanan, waterworks at..... 112
wells at and near..... 111, 113
Burlington, water supply of..... 132
Burlington Township (Lapeer County), plat of, showing well distribution..... 220
wells in..... 220-221, 224
Burnside, wells in and near..... 214, 217, 218-220
Burnside Township (Lapeer County), wells in..... 218-219
Butler, water supply of..... 106

C. Page.

Adillac, elevation near 5
Alhoun County, flowing wells in 132-133
rainfall in 10
topography of 131
village supplies in 132
waterworks in 131-132
wells in 131-133
water of, analyses of 133
temperatures in 16
California, water supply of 105
Cambria, water supply of 100
Cambria Township (Hillsdale County), plat of, showing well distribution 103
wells in 103
Camden, well near 103
Campbell, E. D., analyses by 140, 144
Campbell Township (Ionia County), plat of, showing well distribution 238
wells in 237-238
Cannon Township (Kent County), wells in. 271
Canton Township (Wayne County), wells in 65, 66, 67, 68-69, 70, 76, 77
Capac, waterworks at 205-206, 208
waterworks at, water of, analysis of 206
Carleton, water supply of 163
Carleton region, wells of 38, 44
Carson City waterworks at 249
Cascade, springs on 278
Casco Township (St. Clair County), wells in 204
Cass County flowing wells in 108-109
rainfall in 10
topography of 108
village supplies in 108
waterworks in 109
wells in 108-110
record of 110
temperatures of 16
Cass River, drainage of 213
Cassopolis, water supply of 108
waterworks at 110
Catchments areas, distribution of 5
Cedar Lake, plat of, showing well distribution 247
wells at 246-247
Cedar River, drainage of 164-165
wells on 174
Cement City, water supply at 81
wells at 78
Center Line, wells at 200
Centerville, water supply at 107
water supply at, water of, analysis of 107
Chamberlin, T. C., water-supply data collected by 1
Charlevoix County rainfall in 10
wells in, water of, temperature of 16
Charlotte, waterworks at 166-167
waterworks at, water of, analysis of 167
Charlotte district, wells of 168-169
Cheboygan County, rainfall in 10
wells in, water of temperature of 16
Chelsea, waterworks at 146
waterworks at, water of analysis of 146
Chesterfield Township (Macomb County), wells in 204

Page.

Chester Township (Ottawa County), plat of, showing well distribution 254
wells in 255
Chicago, Lake, location of 6
Christian, E. A., information from 128, 177
Churn drill, well sinking by 13
Clare County, rainfall in 10
wells in, water of, temperature of 16
Clarendon, water supply of 132
Clark, J. E., analyses by 60, 67
Clarks Lake, water supply of 135
wells near 136-137
See also Brooklyn-Clarks Lake-Norvell district.
Clarkston, water supply of 183
Clarksville district, plat of, showing well distribution 238
wells in 237-238
record of 238
water of, analysis of 266
Clayton, water supply of 81
Clifford, wells at and near 217, 221
Climax, water supply of 130
Clinton, wells at and near 78, 80, 81
Clinton River, drainage of 176, 196, 213
wells on 203-204
Clinton County depth to bed rock in 171-172
flowing wells in 175, 225-233
rainfall in 10
topography of 225-226
waterworks in 225, 233-235
wells in 171, 172, 175
records of 226-227, 228, 230, 234
water of, analysis of 266
temperature of 16
Cloverdale, water supply of 163
Clyde, water supply of 183
Clyde Township (St. Clair County), plat of, showing well distribution 210
wells in 210-211
Coal measures, water from 7
Coldwater, waterworks at 104
Coldwater shales, occurrence of 73
water from 67, 140
Coloma, water supply of 113
Columbia Township (Van Buren County), wells in 125
Columbiaville, waterworks at 217
wells near 214, 217, 224-225
Columbus Township (St. Clair County), plat of, showing well distribution 212
wells in 205, 212 213
Concord, water supply of 135
Cone. *See* Milan-Cone district.
Conklin district, plat of, showing well distribution 254
wells in 254 255
Connors Creek, drainage of 55, 58
Constantine, water supply at 107
Cooley, M. E., on rainfall 50
Cooley, Thomas, analysis by 234
Cooper, W. F., information from 109, 203
work of 3, 118, 203

Page.
Coopersville, plat of, showing well distribution..... 255
waterworks at..... 263
wells near..... 255-257
records of..... 256, 263
water of, analysis of..... 266
Covert, water supply of..... 121
Crawford County, rainfall in..... 10
wells in, water of, temperature of..... 16
Crenothrix, occurrence of..... 133
Cressy, water supply of..... 163
Crocker, T. M., on Mount Clemens's wells.. 197
Crockery Creek, wells on..... 259
Crystal Lake district, wells in..... 247-248
Crystal Springs, location of..... 277
Crystal Township (Montcalm County), wells in..... 247-248
Custer Spring, location of..... 277

D.

Davis, Charles A., on Big Meadows district. 188
on Elsie and vicinity..... 230-233
on Groveland Township..... 187-188
on Holly wells..... 180-181
on Imlay City wells..... 214-216
on Lapeer wells..... 216
on Ortonville district..... 184-187
on Oxford wells..... 178-180
work of..... 2, 176
Davisburg, water supply of..... 183
Dayton, water supply of..... 113
Dayton Township (Tuscola County), plat of, showing well distribution... 222
wells in..... 222, 224
Dearborn, water supply of, analyses of.... 68
Dearborn Township (Wayne County), water supply of..... 65
wells in..... 76, 77
Decatur, waterworks at..... 120, 121
Deer Creek, water supply from..... 263
wells on..... 255
Deerfield, wells at..... 81
Defiance moraine, location of..... 138
wells on..... 138
Delray, water supply of..... 53
wells at..... 75
Delta, wells at..... 175
Delta Township (Eaton County), depth to rock in..... 172
Delton, water supply of..... 163
Delwood, wells at..... 175
Dentons, water supply at..... 68, 74
water supply at, analysis of..... 69
Depth, influence of, on temperature..... 14-15
Detroit, population of..... 24
rainfall at..... 49
water supply of..... 24, 53-54
Detroit River, description of..... 52
flow of..... 52
Detroit River, region of, wells of..... 43
Detroit River, water supply from..... 52
water supply from, analyses of... 52, 55-56, 58
contamination of..... 55-58
wells on..... 7
Devereaux, water supply of..... 135
Devonian shales, gas in..... 140
Dexter, water supply of.....
Dimondale, wells at.....
Disco, wells at.....
Dorr, water supply of.....
Douglass, water supply of.....
Dowagiac, water supply of.....
waterworks at.....
wells at and near.....
record of.....
Dowagiac River, drainage of.....
Drainage, character of.....
See also Topography
Drayton Plains, water supply of.....
Drenthe, wells at.....
wells at, record of.....
water of, analysis of.....
Drenthe area, plat of, showing well distribution.....
wells of.....
Drenthe Creek, wells on.....
Drift, Glacial, character of.....
distribution of.....
structure of.....
water from.....
analysis of.....
Drilling, use of.....
Drought, effect of, on wells.....
Drumlins, distribution of.....
Dryden, water-supply of.....
Duffield, S. P., analyses by.....
Dug wells, dangers of.....
description of.....
Dundee, rainfall at.....
Dundee limestone, occurrence of.....
Dundee Township (Monroe County), w in.....
Dunning, water supply of.....
Duplain Township, wells in.....

E.

Eagle, waterworks at.....
East Greenwood district, wells in.....
East Jordan, wells at.....
Easton Township (Ionia County), plat showing well distribution....
wells in.....
East Saugatuck, water supply of.....
Eaton County, depth to rock in.....
flowing wells in..... 136, 165, 168-16
rainfall in.....
topography of.....
waterworks in.....
wells in..... 136, 165, 168-169, 17
temperatures of.....
water of, analysis of.....
See also Lansing.
Eaton Rapids, plat of, showing well distribution.....
waterworks at.....
wells at.....
record of.....
water of, analysis of.....
Eau Claire, waterworks at.....
Ecorse, well at.....
Ecorse River, drainage of.....

Page.

Boorse Township (Wayne County), wells in ... 67, 70, 76
Edmore, waterworks at ... 249-250
waterworks at, water of, analysis of ... 266
Edwardsburg, water supply of ... 108
Elba, water supply of ... 217
Elevations, heights of ... 4-5
Elkton Beach, location of ... 6
Elkise, rainfall at ... 49
water supply at ... 58, 63-64
analysis of ... 64, 75
Elsie, wells at and near ... 230-233
Emmet, water supply of ... 208
Emmet County, ground-water table in ... 11
rainfall in ... 10
wells in, water of, temperature of ... 16
Ensley district, wells of, water of, analysis of ... 266
Erie lobe, location of ... 213
Erie Township (Monroe County), wells in ... 32
Essex Township (Clinton County), wells in, water of, analysis of ... 266
Eureka, wells at ... 226-227
wells at, records of ... 226-227
Eureka district, plat of, showing well distribution ... 226
wells in ... 225-228
water of, analysis of ... 266
Exeter Township (Monroe County), wells in ... 27, 30, 35-38, 42

F.

Fairfield, wells at ... 81
Fairhaven, wells at ... 204-205
Farmington, water supply of ... 183
Farmington Township (Oakland County), wells in ... 189, 194
Feeble-minded, Home for, waterworks at ... 216-217
Fennville, water supply of ... 153
Fish Creek, drainage of ... 249
Fish Lake, well on ... 109
Flat River, description of ... 267
water supply from ... 236, 269
wells on ... 235, 251
Flint River, drainage of ... 176, 213
wells on ... 224
Flowing wells. *See* Wells, flowing; *also particular counties.*
Ford, water supply of ... 54, 58
Forest beaches (upper and lower), location of ... 6
Forests, distribution of ... 5
Fowler, waterworks at ... 234
Fowlerville, wells in ... 175
Francisco, water supply of ... 135
Franklin Township (Lenawee County), plat of, showing well distribution ... 95
wells in ... 95-97, 98
Franklin, water supply of ... 183
Fraser, wells at ... 200
Freeport, water supply of ... 163
Fremont Township (Sanilac County), wells in ... 209
Frenchtown Township (Monroe County), wells in ... 30
Fuller, M. L., on loss of head ... 26
on lower Huron River region ... 33-48
work of ... 3, 4, 33
Fulton, waterworks at ... 129, 130

G.

Page.

Galbraith, I. B., information from ... 120
Galesburg, water supply of ... 130
Galien, wells at and near ... 111, 113
Galien district, wells in ... 113-114
Gearey, wells in ... 175
Gelston, L. M., analysis by ... 59
Genesee County, rainfall in ... 10
wells in, water of, temperature of ... 16
Geneva Township (Van Buren County), wells in ... 125
Geography, description of ... 4-6
Geologic history, outline of ... 4-6
Geologic map of Michigan ... 8
Geology, account of ... 4-9
Girard, water supply of ... 105
Glacial epoch, history of ... 4-6
Glacial lakes, description of ... 6
Glaciers, distribution and character of ... 4-6
Gladwin County, rainfall in ... 10
wells in, water of, temperature of ... 16
Glenwood, water supply of ... 108
wells at and near ... 108, 109
Glenwood district, wells in ... 108
Gobleville, water supply of ... 121
Goguac Lake, water supply of ... 131
Goodells, water supply of ... 208
Graatschap area, wells in ... 155
Grand Haven, rainfall at and near ... 11
waterworks at ... 260-263
water of, analysis of ... 262-263
wells at, record of ... 261
Grand Junction, water supply of ... 121
Grand Ledge, waterworks at ... 174
Grand Rapids, waterworks at ... 268-269
wells at and near ... 7, 272-273, 277
Grand River, description of ... 267
drainage of ... 134, 139, 164, 235, 267
water supply from ... 269
wells on ... 135-136, 174, 241
location of, figure showing ... 241
Grand River Valley district, wells in ... 272-274, 277
Grand Traverse Bay, wells near ... 16
Grand Traverse County, rainfall in ... 10
wells in, water of, temperature of ... 16
Grandville, plat of, showing well distribution ... 273
waterworks at ... 273
wells at ... 273
Grant Township (St. Clair County), wells in ... 209
Grape, rainfall at ... 49
Grasmere beach, location of ... 6
Grass Lake, water supply of ... 135
Gratiot County, rainfall in ... 10
wells in ... 225, 227
water of, temperature of ... 16
Greenbush Township (Clinton County), plats of, showing well distribution ... 226, 229
wells in ... 225-227, 229, 230
Greenfield Township (Wayne County), wells in ... 77
Greenville, waterworks at ... 250-251
well of, record of ... 250
water of, analysis of ... 266
Greenwood Township (St. Clair County), wells in ... 20

Page.
Gregory, W. M., information from..... 41
work of..... 3
Grosse Isle, wells of..... 43-44, 76
See also Swan well.
Grossepoint farms, water supply of..... 51
Grossepoint Township (Wayne County), water supply of..... 51, 68, 77
Ground-water table, depth of..... 11-12
Groveland Township (Oakland County), wells of..... 187-188
Gypsum, influence of, on water..... 14

H.

Hadley, wells near..... 214, 217
Hale, A. K., information from..... 143
Hale Creek, drainage of..... 58
Hamilton, water supply of..... 153
Hamtramck, water supply of..... 53
Hamtramck Township (Wayne County), wells in..... 65, 77
Hanover, water supply of..... 135
Harrisburg, wells at..... 259-260
wells at, record of..... 260
Harrisburg area, plat of, showing well distribution..... 259
wells in..... 259-260
water of, analysis of..... 266
Harrison Springs, location of..... 278
Hartford, waterworks at..... 120
water supply at..... 121
water of, analysis of..... 121
Hartford Township (Van Buren County), wells in..... 121-122
Haslet Park, wells in..... 175
Hastings, waterworks at..... 161-162, 163
waterworks at, water of, analysis of... 162
Head, loss of..... 22-23, 33-48
Headlands, distribution of..... 5
Hickory Corners, water supply of..... 163
Highland Park, water supply of..... 53
Hilliards, water supply of..... 153
Hillsdale, waterworks at..... 99
Hillsdale County, flowing wells in.. 98-99, 100-103
rainfall in..... 10
topography of..... 98
village supplies in..... 100
waterworks in..... 99-100
wells in..... 98-103
water of, analysis of..... 99
temperature of..... 16
Holland, waterworks at..... 263-265
waterworks at, water of, analysis of... 265
wells at, record of..... 265
Holloway, wells at..... 81
Holloway district, plat of, showing well distribution..... 87
wells of..... 87-89
Holly, waterworks at..... 180-181
wells at and near..... 177, 181
record of..... 181
water of, analysis of..... 181
Holt, wells in..... 175
Homer, water supply of..... 132
Hooper, water supply of..... 153
Hopkins, water supply of..... 153

Page.
Hopkins Township (Allegan County), plat of, showing well distribution... 156
Horton, water supply of..... 135
Horton, R. E., work of..... 3
Howard City, waterworks at..... 251
wells at..... 251
water of, analysis of..... 266
Hubbardston, wells in..... 239
wells in, record of..... 239
Hubbardston district, wells in..... 239-240
Hudson, waterworks at..... 80
Hudson Township (Lenawee County), well in..... 95
Huron lobe, location of..... 213
Huron River, course of..... 25, 58
drainage of..... 139, 164, 176
low water in, effect of..... 46
pollution of..... 60
region of, geology of..... 34-35
rainfall in..... 47-48
topography of..... 33-34
water supplies of..... 33, 35-48
decline of..... 33, 44-47
wells on..... 48, 68, 138-145
Huron Township (Wayne County), wells in. 41
Hurty, J. U., analysis by..... 262
on Grand Haven water..... 262

I.

Ida Township (Monroe County), wells in... 31
Illinoian stage, drift of..... 8
Imlay City, waterworks at..... 214-216
wells at..... 217
wells at, record of..... 215
water of, analyses of..... 215
Imlay Township (Lapeer County), wells in..... 214-216
Ingham County, depth to rock in..... 171
flowing wells in..... 136, 169-170, 174-175
rainfall in..... 10
topography of..... 114-165
waterworks in..... 168, 173-174
wells in..... 136, 169-170, 173-175
record of..... 170
water of, analyses of..... 172-173
temperature of..... 16
See also Lansing.
Insane Asylum, well at..... 177-178
well at, record of..... 177
Institutions, water supplies of..... 23-24
Intermediate Lake, wells on..... 23, 16
Ionia, waterworks at..... 243
Ionia County, flowing wells in..... 235-244
rainfall in..... 10
springs in..... 239-240, 246
waterworks in..... 244-246
wells in..... 235-244, 245-246
records of..... 235-236, 238, 239, 242-243
water of, analyses of..... 244, 246
temperature of..... 16
Ionia district, springs in..... 240
wells in..... 240-244
records of..... 242-243
water of, analysis of..... 244

Page.
ıia Township (Ionia County), plat of, showing well distribution..... 241
wells in..... 242
ɔn, presence of..... 14
ɔquois Lake, location of..... 6
ring, water supply of..... 163
abella County, rainfall in..... 10
wells in, water of, temperature of..... 16

J.

ıckson, water supply of..... 24
waterworks at..... 134-135
wells at..... 135-136
ackson County, flowing wells in..... 135-137
rainfall in..... 10
topography of..... 133
village supplies in..... 135
waterworks in..... 134-135
wells in..... 134-137
water of, temperatures of..... 16
Jasper, wells at..... 81-82
Jeddo, water supply of..... 208
Jefferson, M. S. W., on rainfall..... 50
Jerome, wells at..... 101-102
Jones, water supply of..... 108
Jonesville, waterworks at..... 99
waterworks at, water of, analysis of... 99
Joppa, water supply of..... 132

K.

Kalamazoo, waterworks at..... 127-129
wells at and near..... 130
water of, analyses of..... 129
Kalamazoo County, flowing wells in..... 130
rainfall in..... 10
topography of..... 127
village supplies in..... 130
waterworks in..... 127
wells in..... 127-130
water of, analyses of..... 129
temperatures of..... 16
Kalamazoo moraine, location and character of..... 119, 127, 152, 160
Kalamazoo River, drainage of..... 127, 131, 134, 152, 164
wells on..... 127, 131, 132, 155
Kalkaska County, rainfall in..... 10
wells in, water of, temperature of..... 16
Kathairo water. *See* Swan well.
Kedzie, R. C., analyses by..... 166, 173, 183, 215, 246, 252, 263
Keeler, water supply of..... 121
Kendall, water supply of..... 121
Kent County, drainage of..... 267-268
flowing wells in..... 270-276
rainfall in..... 10
springs in..... 217
water power in..... 267-268
waterworks in..... 268-270
wells in..... 268-277
records of..... 275
water of, analysis of..... 271
temperatures of..... 16
Kibbie, water supply of..... 121
Kimball, water supply of..... 208

Page.
Kimball Township (St. Clair County), wells in..... 211-212
Kinderhook, water supply of..... 105
Kings Mill, water supply of..... 217
Klingers Lake, water supply at..... 105-106
water supply at, water of, analysis of.. 106

L.

Lacota, water supply of..... 121
Laingsburg, wells in..... 175
Lake Border moraine, location of..... 119
Lake County, rainfall in..... 10
wells in, water of, temperature of..... 16
Lake Odessa, waterworks at..... 244-245
Lakes, occurrence of..... 5
water supply from..... 24
Lakes, Glacial, description of..... 6, 8
Lane, A. C., on Kent County salt wells.... 277
on Lansing and vicinity..... 170-175
on rainfall..... 50
work of..... 1, 3, 14, 33, 133
Lansing, vicinity of, drift in..... 171-172
vicinity of, flowing wells of..... 174-175
geology of..... 170-172
water supply of..... 170-175
water supply of..... 24
waterworks of..... 173-174
wells at..... 173-175
water of, analyses of..... 172-173
Lansing Township (Ingham County), wells in..... 175
Lapeer, waterworks at..... 216-217
wells at..... 214
Lapeer County, flowing wells in..... 218-225
rainfall in..... 10
topography of..... 213-214
village supplies in..... 217
waterworks in..... 214-217
wells in..... 214-225
record of..... 215
water of, analyses of..... 215
temperatures of..... 16
Lasalle Township (Monroe County), wells in..... 32
Latitude, influence of, on temperature of underground water..... 15
Lawrence, waterworks at..... 120, 121
Lawton, water supply of..... 121
wells near..... 123
Lee, water supply of..... 153
Leelanaw County, rainfall in..... 10
wells in, water in, temperature of..... 16
Legislation, character and text of..... 21-22
Leighton, M. O., analyses furnished by..... 68, 69, 88, 92-93, 99-100, 104, 106-107, 121, 122-123, 129, 146, 147, 151, 155, 160, 178, 181, 198, 199, 206, 208, 215, 243-244, 265
Leighton Township (Allegan County), plat of, showing well distribution... 156
Lenawee County, flowing wells in.... 28, 78, 82-98
location of..... 78
map of..... 28
rainfall in..... 10
topography of..... 78
village supplies in..... 80-82

Page.
Lenawee County, waterworks in..... 79–80
wells in..... 7, 78, 82–98
water in, analyses of..... 79, 88
temperature of..... 16
Lenox, waterworks at..... 198
waterworks at, water of, analyses of... 198
Leonard, water supply of..... 183
Leslie, wells at..... 136, 169–170
wells at, water of, analyses of..... 170
Leslie district, wells in..... 169–170
Leverett, Frank, information from..... 41, 114, 123, 125
introduction by..... 1–24
on Allegan County..... 152–160
on Barry County..... 160–164
on Berrien County..... 110–118
on Branch County..... 104–105
on Calhoun County..... 131–133
on Cass County..... 108–110
on Eaton County..... 164–165
on Hillsdale County..... 98–103
on Ingham County..... 164–165
on Jackson County..... 133–137
on Kalamazoo County..... 127–130
on Lapeer County..... 213–225
on Lenawee County..... 78–98
on Macomb County..... 196–205
on Monroe County..... 25–32
on Oakland County..... 176–196
on St. Clair County..... 205–213
on St. Joseph County..... 105–107
on Troy district..... 188–194
on Van Buren County..... 119–126
on Washtenaw County..... 138–160
on Willow wells..... 36
work of..... 3, 26, 33
Lewis, S. J., analyses by..... 68, 69, 88, 99, 100, 104, 106, 107, 121, 123, 129, 146, 147, 151, 155, 160, 178, 179, 181, 191–192, 198, 199, 206, 208, 215, 244, 265
work of..... 3, 14, 82
Limestone, water from..... 7
Litchfield, water supply of..... 100
Livingston County, rainfall in..... 10
wells in..... 175
water of, temperature of..... 16
Livonia Township (Wayne County), springs in..... 63
wells in..... 70, 77
Lockport Township (St. Joseph County), wells in..... 106
London Township (Monroe County), wells of..... 28, 29
Long Lake, wells near..... 109
Lowell, waterworks at..... 270, 274
wells at..... 274
Lum, wells near..... 214, 217, 218
Lyons, waterworks at..... 245

M.

McLouth, C. D., work of..... 3
Macomb County, flowing wells in 197, 201–205
rainfall in..... 10
topography of..... 196–197
Macomb County, village supplies in .....
waterworks in..... 19
wells in..... 188, 192, 19
water of, temperatures of .....
Macon River, course of.....
Macon Township (Lenawee County), map of.....
wells of..... 83,
Manchester, water supply of.....
wells in..... 139, 15
water of, analysis of.....
Manchester district, wells in..... 15
Manistee County, rainfall in.....
wells in, water of, temperature of.....
Map of Michigan, showing area reported on
showing ground-water temperatures...
See also Artesian map; Geologic map.
Maplegrove, water supply of .....
Maple Rapids, wells at and near.....
wells at and near, record of.....
Maple Rapids district, wells in.....
Maple River, water supply from.....
Marcellus, water supply of.....
waterworks at.....
wells near.....
Marengo, water supply of.....
Marine City, waterworks at..... 205
Mariette moraine, location and character of..... 222
Marls, water from.....
Marshall, waterworks at.....
Marshall sandstones, occurrence of..... 133,
water from..... 7, 131, 216–217,
Martin, water supply of.....
Marysville, water supply of.....
Mason, waterworks at.....
wells at.....
Mason County, rainfall in.....
wells in, water of, temperature of.....
Mattawan, water supply of.....
Maumee, Lake, location and history of..... 6,
Mecosta County, rainfall in.....
wells in, water of, temperature of.....
Medina, well in.....
Meridian, wells in.....
Meridian Township (Ingham County), depth to rock in.....
Metamora, water supply of.....
Michigan, Lake, water supply from.....
water table near.....
Middleville, water supply of.....
Midland County, rainfall in.....
wells of, water of, temperature of.....
Milan, water supply of..... 139–140,
water supply of, analyses of.....
wells in.....
Milan-Cone district, map of.....
wells in..... 2
Milan Township (Monroe County), map of.
wells of..... 2
Milford, waterworks at..... 178
waterworks at, water of, analysis of...
Mill Creek (Kent County), springs on.....
Mill Creek (St. Clair County), drainage of..
Milletts, wells at.....
Missaukee County, rainfall in.....
wells of, water of, temperature of.....

Page.
Moline, water supply of ... 153
Monguanon Creek, drainage of ... 58
Monguanon Township (Wayne County), wells in ... 65, 76
Monroe, wells at and near ... 32
Monroe beds, occurrence of ... 35, 73
Monroe County, artesian belts in ... 25
flowing wells in ... 25-32
location of ... 25
map of ... 28
rainfall in ... 10
Sylvania sandstone in, water in ... 75
topography of ... 25
wells in ... 7, 25-32
water of ... 33
temperature of ... 16
Montcalm County, flowing wells in ... 246-249
rainfall in ... 10
springs in ... 254
waterworks in ... 249-253
wells in ... 239, 246-523
records of ... 249, 250
water of, analyses of ... 252, 253, 267
temperature of ... 16
Monterey Township (Allegan County), plat of, showing well distribution ... 156
Moraines, character and distribution of ... 4-6
Morenci, plat of, showing well distribution ... 92
water supply of ... 80
wells at ... 82, 91-93
water of, analysis of ... 93
Morgan, water supply of ... 163
Morrice, wells in ... 175
Moscow Township (Hillsdale County), well in ... 102
Mosberville, water supply of ... 100
Mount Clemens, waterworks at ... 197-198
wells at and near ... 197, 198, 204
Muir, waterworks at ... 245
Municipal water supplies, statistics of ... 23-24
Muskegon River, source and course of ... 5

N.

Nankin Township (Wayne County), wells in 66, 77
Napoleon, water supply of ... 135
Nashville, waterworks at ... 162, 163
Nellist, J. F., work of ... 3
Newaygo County, rainfall in ... 10
wells in, water of, analysis of ... 266
water of, temperature of ... 16
New Baltimore, waterworks at ... 198
New Buffalo, water supply of ... 113, 114
New Buffalo district, wells in ... 114
Newburg, water supply of ... 108
New Haven, wells at and near ... 183, 204
Newport quarry, effect of, on wells ... 46
New Richmond, water supply of ... 153
New Troy, water supply of ... 113
Niles, waterworks of ... 111-112, 113
Nipissing, Lake and beach, location of ... 6
North Adams, water supply of ... 100
North Branch, wells near ... 214, 217
North Branch Township (Lapeer County), plat of, showing well distribution ... 220
wells in ... 220-221
North Macon Creek, wells on ... 86
North Plains Township (Ionia County), spring in ... 239-240
wells in ... 239
North Steel station, wells near ... 210-211
Northville, fish hatchery at, springs at ... 71
fish hatchery at, springs at, view of ... 44
water supply of ... 71-72
Northville Township (Wayne County), lake in ... 51
springs in ... 71
Norvell, water supply of ... 135
wells near ... 136
See also Brooklyn—Clarks Lake—Norvell district.
Novi, water supply of ... 183

O.

Oakland County, flowing wells in ... 176, 183-196
rainfall in ... 10
topography of ... 176
village supplies in ... 183
waterworks in ... 177-183
wells in ... 176-177
records of ... 177, 181
water of, analyses of ... 178, 179, 181, 182, 183, 186, 192
temperature of ... 16
Oceana County, rainfall in ... 10
wells in, water of, temperature of ... 16
Ogden Center, wells at and near ... 89
Ogden Township (Lenawee County), plat of, showing well distribution ... 90
wells in ... 89-91
Ogemaw County, rainfall in ... 10
wells in, water of, temperature of ... 16
Ohio Corners, water supply of ... 153
Okemos, wells in ... 175
Oneida Township (Eaton County), depth to rock in ... 172
Onondaga, wells at ... 136
Onsted, water supply at ... 81
Orangeville, water supply of ... 163
Orchard Lake, water supply of ... 183
Orion, depth to rock at ... 177
Ortonville, plat of, showing well distribution ... 185
section at, figure showing ... 184
wells at ... 184-187
water of, analysis of ... 186
Ortonville district, wells of ... 184-187
Osceola County, elevations in ... 5
rainfall in ... 10
wells in, water of, temperature of ... 16
Oshtemo, waterworks at ... 129, 130
Otsego, waterworks at ... 153
See also Watson—Otsego district.
Otsego County, rainfall in ... 10
wells in, water of, temperature of ... 16
Otsego Township (Allegan County), plat of, showing well distribution ... 154
wells in ... 154
Otsico Township (Ionia County), wells in. 235-237
Ottawa County, flowing wells in ... 254-260
rainfall in ... 10
topography of ... 254

Page.
Ottawa County, waterworks in 260-266
wells in 7, 254-266
records of 255-256, 257, 258-259, 260, 261, 263, 265
water of, analyses of 262-263, 265, 266
temperature of 16
Otter Lake, water supply of 217
Ovid, waterworks at 233
waterworks at, water of, analysis of ... 266
Ovid Township (Clinton County), wells in. 230
Ovitz, F. K., analysis by 44
Oxford, ground-water conditions at, figures showing 179, 180
water supply of 183
dangerous character of 179-180
waterworks at 178-180
water of, analysis of 179
Oxford Township (Oakland County), wells in 178-180

P.

Palmyra Township (Lenawee County), plat of, showing well distribution ... 87
wells in 89
Pantlands Springs, location of 277
Paris Township (Kent County), springs in. 277
wells at 271
analysis of 271
Parma, water supply of 135
Partello, water supply of 132
Pawpaw, waterworks at 120, 121, 122
wells at and near 122-123
water of, analysis of 123
Pawpaw Lake, wells on 118
Pawpaw River, location of 119
wells on 121-122
Pawpaw Township (Van Buren County), wells in 122-123
Penn, water supply of 108
Perry, wells in 175
Pine Creek, wells on 122, 126
Pine Grove Township (Van Buren County), wells in 126
Pine Lake, wells on 8
Pine River, drainage of 205
Pipestone district, plat of, showing well distribution 115
wells in 114-117
Pipestone Township (Berrien County), plat of, showing well distribution 115
wells in 111, 114-117
Pittsfield, water supply of 100
Pittsfield Township (Washtenaw County), wells in 148
Pittsfield Junction district, wells of 147-149
Plainwell, waterworks at 153
Plymouth, mineral water at 66-67
mineral water at, analysis of 67
water supply of 71-72
Plymouth Rock mineral water, analysis of. 67
source of 66-67
Plymouth Township (Wayne County), springs in 71
wells in 70, 77

Pa
Points, well, use of .....
Pokagon Township (Cass County), wells in
Polglase, W. A., information from .....
Ponce de Leon water, analysis of .....
Pontiac, depth to rock at .....
water supply of 177
well at, record of .....
Population, estimates of 4, 2
Portage, water supply of .....
Portage Creek, wells on .....
Port Huron, rainfall at and near .....
waterworks at 205
Port Huron moraine, location of .....
Portland, water at, analysis of .....
waterworks at 245
Prairieville, water supply of .....
Precipitation, records of 1
Prescott, A. B., analysis by .....
Presque Isle County, rainfall in .....
wells in, water of, temperature of .....
Pulaski, water supply of .....

Q.

Quincy, waterworks at .....
waterworks at, water of, analysis of ..
wells at .....

R.

Rabbit River, wells on .....
Rainfall, effect of, on wells 4
records of 10-1
Raisin Center, wells at .....
Raisin River, course of 2
drainage of .....
water supply from 79
wells on .....
Raisin Township (Lenawee County), plat of, showing well distribution ..
wells in .....
Raisinville Township (Monroe County), wells in .....
Ransom Township (Hillsdale County), plat of, showing well distribution 1
wells in 99, 1
Rattle Run, wells on 2
Ray Township (Wayne County), plat of, showing well distribution 2
wells in 2
Reading, waterworks at 99-
wells near .....
water of, analysis of .....
Redford Township (Wayne County), wells in .....
Richland, water supply of .....
Richmond, waterworks at .....
waterworks at, water of, analysis of ...
Rich Township (Lapeer County), plat of, showing well distribution .....
wells in 221-
Ridgeway, wells at .....
Ridgeway Township (Lenawee County), plat of, showing well distribution .....
River Rouge, description of .....

Page.
River Rouge, drainage of 139, 176
water of, analysis of 59–60
pollution of 58–60
water supply from 53
wells on 189
Rivers, course of 5
supply of 9
water supply from 24
See also Topography.
Riverside, water supply of 113
River Junction, water supply of 135
Rochester, plat of, showing well distribution 195
waterworks at 182–182, 183
waterworks at, water of, analysis of 183
wells in 195
Rock, water from 25
Rockford, waterworks at 270
Rockwood region, wells of 41–42, 44
Rollin, wells at and near 95
Rollin Township, plat of, showing well distribution 94
wells in 94–95
Rome Township (Lenawee County), wells in 98
Romeo, waterworks at 199
waterworks at, water of, analysis of 199
Romulus Township (Wayne County), water supply of 65
wells in 77
Roscommon County, rainfall in 10
wells in, water of, temperature of 16
Rose Center, water supply of 183
Roseville, wells at and near 200, 203
Rouge River. See River Rouge.
Roxana Township (Eaton County), depth to rock in 172
wells in 169, 175
Royal Oak, depth to rock at 177
water supply of 183
Royal Oak Township (Oakland County), wells in 188, 194
Rush Lake, well near 121
Russell, I. C., on Ann Arbor waterworks 143
Russell, T., on Michigan weather 11

S.

Saginaw, Lake, location of 6
Saginaw Bay, wells at and near, head in 23
Saginaw County, rainfall in 10
wells in, water of, temperature of 16
Saginaw lobe, description and location of 4–5, 131, 169, 176, 21
St. Clair, waterworks at 205, 208
St. Clair, Lake, character of 52
shore of, wells on 203, 205
utilization of 54
water supply from 108
wells on 7
St. Clair County, flowing wells in 209, 213
location of 205
rainfall in 10
topography of 205
village supplies in 209
St. Clair County, waterworks in 205–208
wells in 204, 205–213
records of 207
water of, analyses of 206, 208
temperature of 16
St. Clair River, contamination of 56
wells on 7
St. Johns, waterworks at 233–234
wells at, record of 234
water of, analysis of 234
St. Johns district, wells in 228–230
water of, analysis of 266
St. Joseph, waterworks at 112, 113
St. Joseph County, flowing wells in 105–106
rainfall in 10
topography of 105
waterworks in 106–107
wells in 105–107
water of, analyses of 106, 107
temperature of 16
St. Joseph River, drainage of 110, 127
wells on 112
Saline, water supply of 139, 147
Saline River, course of 25
water supply from 139
Saline Township (Monroe County), map of 28
wells of 85, 86
Salts, presence of 14
Sand, occurrence of 25
texture of 9
relation of water supply and 9
water from 25
Sand Creek, wells near 91
Sand Lake, wells at 275–276
wells at, records of 275
Sand Plains, occurrence of 5
Sandstone, water from 7
Sanilac County, rainfall in 10
wells in 209
water of, temperature of 16
Saugatuck, water supply of 153
Sawyer, water supply of ..... 1[illegible]3
Schoolcraft, water supply of ..... 1[illegible]0
School Creek, wells on ..... 163–1[illegible]4
Shaftsburg, wells in ..... 1[illegible]5
Sharon Township (Washtenaw County), plat of, showing well distribution ..... 1[illegible]9
wells in ..... 149–1[illegible]0
Shelbyville, water supply of ..... 1[illegible]3
Shepardsville, well near, record of ..... 2[illegible]0
Shepardsville district, wells in ..... 2[illegible]0
Sherwood, wells at and near ..... 104, 1[illegible]5
Sherzer, W. H., information from ..... [illegible]5
on Huron River region ..... 44–[illegible]5
on Monroe County wells 29
on Wayne County 48–77
work of ..... 3–26, [illegible]3
Shiawassee County, rainfall in 10
wells in 175
water of, temperature of 16
Shiawassee River, drainage of 176
Sidney, well near 244
Sickles, Mary, information from 80
Silver Creek, wells near 214

Page.
Silver Creek Township (Cass County), wells in 109
Silverwood, water supply of 217, 224
Silverwood district, plat of, showing well distribution 222
wells in 221-224
Smiths Creek, wells at and near .. 205, 208, 211-212
Soils, buried, occurrence of 8
Soldiers Home, waterworks at 270
South Arm, wells at 8
South Black River, drainage of 119
Southfield, water supply of 183
Southfield Township (Oakland County), wells in 188-189, 191, 194
South Haven, waterworks at 120-121
South Lyon, water supply of 183
Sparta, waterworks at 270
wells at 271
Spring Arbor, water supply of 135
Springport, water supply of 135
Springwells Township (Wayne County), wells in 67, 70, 76
Stanton, water at, analyses of 252, 253
waterworks at 252-253
State Industrial Home for Girls, water supply for 80
Steere celery farm, wells at 138, 147-148
wells at, analysis of 149
Sterling Township (Macomb County), wells in 188, 192, 203
Stevensville, water supply of 113
Stone Lake, water from 110
Stony Creek, course of 25
Streams. *See* Rivers.
Sturgis, water supply at 107
water of, analysis of 107
Sulphur, presence of 14, 25-26
Summerfield Township (Monroe County), wells in 31
Sunfield, wells at 175
Swan, James, information from 33
Swan Creek, course of 25
wells on and near 33, 38-40, 44
Swan well, description of 43-44, 74
effects of 45-46
history of 43-44
view of 44
water from, analysis of 44
Sycamore Creek, wells on 175
Sylvania sandstone, occurrence of 35, 73
water from 7, 38, 41, 75

T.

Taylor, E. B., on Michigan Soldiers' Home water 270
Taylor Township (Wayne County), wells in 67, 76
Tecumseh, waterworks of 80
wells near 78, 80
Tekonsha, water supply of 132
Temperatures of well water, map showing ... 17
records of 14-20, 68
Thornapple River, description of 267-268
drainage of 164
Thomas, water supply of 183
Three Oaks, waterworks at 112, 113
Three Rivers, water supply at 105, 106-
water supply at, water of, analysis of ...
Tiffin River, drainage of .....
wells on 91
Tipton, wells in .....
Tipton district, plat showing well distribution .....
wells in 95
Topography, outline of .....
See also particular counties.
Traverse City, wells at .....
Troy district, flowing wells in .....
Trenching, advantage of, in obtaining flow, figure showing 1
Trenton, water supply of 54, 55,
Trowbridge Station, wells at 1
Troy, water supply of 1
Troy district, drift of 1
plat of, showing topography 1
section of, figure showing 1
wells in 188-1
water of, analysis of 1
Troy Township (Oakland County), wells in 188, 191, 192-1
Tubular wells, description of 1
Tuscola County, rainfall in 1
wells in 222, 2
water of, temperature of 1
Typhoid fever, occurrence of 24, 56-57, 8

U.

Udden, J. A., analyses by 18
information from 112-11
120, 122, 123, 125, 152, 20
on Avon Township 195-19
on Birmingham wells 18
on Rochester wells 182-18
on Troy district 188-19
work of ... 2, 3, 79, 82, 88, 91, 94, 100, 102, 116, 11
122, 125, 130, 137, 155, 176, 202, 2
Union City, waterworks at 1
wells near 1
Utica, wells at 200, 202-2
Utica area, wells in 202-2

V.

Valparaiso moraine, location and character of 111, 113, 119,
Van Buren County, flowing wells in 121-
rainfall in .....
springs of .....
topography of .....
village supplies in .....
waterworks in 120-
wells in 120-
water of, analysis of .....
temperature of .....
Van Buren Township (Wayne County), water supply of 65, 66,
wells in 70, 76,
Vandalia, water supply of 1
Vaughan, V. C., analysis by 1
on typhoid fever 57,
work of .....
Vermontville, wells at .....
Vevay Township (Ingham County), wells in .....

Page.
ksburg, waterworks at..... 129, 130
ctor Township (Clinton County), depth to rock in..... 172
llage supplies. *See particular counties.*
lneland, water supply of..... 113
scosity Oil Company, analysis by..... 162

W.

Wadhams, water supply of..... 208
Wakelee, water supply of..... 108
Waldenburg, wells at..... 200
Waldron, water supply of..... 100
Walled Lake, water supply of..... 183
Warren, wells at..... 200
Warren Lake, location of..... 6, 25, 211
Washington wells at..... 200
Washington-Ray district, plat of, showing well distribution..... 201
wells in..... 202
Washington Township (Gratiot County), plat of, showing well distribution..... 226.
wells in..... 225, 227
Washington Township (Macomb County), plat of, showing well distribution..... 201
wells in..... 202
Washtenaw County, flowing wells in..... 128, 138, 140–141, 147
gas in..... 140
rainfall in..... 10
springs in..... 139
topography of..... 138
village supplies in..... 146–147
waterworks in..... 140, 142–146
wells in..... 7, 138–151
record of..... 145
water of, analyses of..... 146
144, 146, 147, 149, 151
temperature of..... 16, 148, 149
Waste, restriction of 13, 21–22
Water, underground occurrence of..... 7–8
quality of 14
temperatures of..... 14–20
map showing 17
Water-bearing formations, distribution of. 7–8
distribution of map showing..... 6
Waterford water supply of 183
Waterloo, water supply of..... 135
Watervliet, wells at and near..... 111, 113
Watervliet Township (Berrien County), plat of, showing well distribution..... 118
wells in..... 117–118
Waterworks, statistics of..... 23–24
See also particular counties.
Watson, water supply of..... 153
wells at and near..... 153–155
Watson-Otsego district, plat of, showing well distribution..... 154
wells in..... 153–155
water of, analysis of..... 155
Watson Township (Allegan County), plat of, showing well distribution..... 154
wells in..... 154–155
water of, analysis of..... 155

Page.
Waverly, wells near..... 124
Waverly Township (Van Buren County), plat of, showing well distribution..... 123
wells in..... 123–124
Wayland, water supply of..... 153
wells at and near 7
Wayland district, location of..... 154
plat of, showing well distribution..... 156
wells of..... 155–160
records of..... 158–159
water of, analysis of..... 160
Wayland Township (Allegan County), plat of, showing well distribution... 156
Wayne, water supply of..... 63
water supply of, analysis of..... 69
Wayne County artesian belts in..... 67
bed rock in character of..... 73
water of..... 73–77
analyses of..... 68
flowing wells in..... 67–70, 73–74
geology of..... 73
Glacial deposits in, character of..... 64–65
water of..... 65–72
analyses of..... 68
ground water in..... 60–77
analyses of 64
lake and river deposits in, character of. 60–61
water of..... 61–64
lakes in..... 51
location of..... 48
mineral water in..... 66–67
population of..... 48
rainfall in..... 10, 49–50
reservoirs in..... 50–51
springs in..... 63, 71–72, 74
streams in..... 52–60
surface waters of..... 50–60
analyses of..... 55–56, 58, 59, 60
topography of..... 58, 60–61
water of, contamination of..... 55–58
waterworks in..... 51, 53–55, 59, 60
wells in..... 7, 61, 65–70, 73–77
water of..... 33
analyses of..... 68, 69, 70, 75
contamination of..... 62
temperature of..... 16
Wayne County Infirmary, water supply of..... 59, 63–64
water supply of, analysis of..... 64, 75
Weather Bureau, United States, records of. 10–11
Webberville, wells in..... 175
Weesaw Township (Berrien County), wells in..... 114
Well points, use of..... 13
Wells, boring of, methods of..... 237
descriptions of..... 12–13
flow from, obtained by trenching, figure showing 229
water of temperature of..... 16, 68
map showing..... 17
water supply from..... 24
See also particular localities.
Wells, flowing, character of..... 9, 22
defects in..... 23
districts of..... 22
head of..... 22–23

Page.
Wells, flowing, occurrence of..... 8
use of..... 22
waste from..... 13, 21-22
water supply from..... 24
See also particular localities.
West Holt, wells at..... 175
Weston, wells at..... 80, 82
Wexford County, rainfall in..... 10
wells in, water of, temperature of..... 16
Wheatland Township, well in..... 102
White Fish Lake, well at..... 248-249
well at, record of..... 249
Whiteford Township (Monroe County), wells in..... 31
Whitneyville Springs, location of..... 278
Whittlesey Lake, location of..... 6, 25, 67
Williams, G. S., on river contamination.... 56-57
Williamsburg, wells at..... 16
Williamston, wells in..... 175
Willow, wells at and near..... 36
Willow-Exeter region, wells of..... 35-38, 44
Winchell, A., on Kent County salt wells.... 277
Windmills, use of..... 13
Winfield, well at..... 136
Winter, effects of, on wells..... 46-47
Wisconsin stage, drift of..... 8
Wixom, water supply of..... 183
Wolf Creek, wells at..... 97-98
Wolf Creek district, wells of..... 97-98
Woodland, water supply of..... 163
wells near..... 163
Woodland Center, wells near..... 163, 164
Woodmere, water supply of..... 53
Woodstock, water supply of..... 51
Wright Township (Ottawa County), plat of, showing well distribution... 254
wells in..... 255
Wyandotte, water supply of..... 54, 57-58
water supply of, analyses of..... 58

Y.

Yale, waterworks at..... 205, 206-208
wells at, records of..... 207
water of, analysis of..... 208
Yale moraine, location of..... 209
Yerkes Lake, data on..... 51, 71
York, plat of, showing well distribution... 82
York district, map of..... 28
wells of..... 82-86
York Township (Washtenaw County), map of..... 28
wells of..... 85-86
Yorkville, water supply of..... 130
Ypsilanti, drilling apparatus used at, view of..... 140
rainfall at..... 49
water supply of..... 145
wells at..... 138, 140
record of..... 145
Ypsilanti Township (Washtenaw County), wells in..... 138

Z.

Zeeland, waterworks at..... 265-266
Zeeland Township (Ottawa County), wells in..... 527-258

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 182.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at practically cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities thruout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the sixty-second in Series O, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)

WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)

WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)

WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)

WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls. (Out of stock.)

WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp. (Out of stock.)

WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls. (Out of stock.)

WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)

WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.

WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)

WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp. (Out of stock.)

WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls. (Out of stock.)

WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)

WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)

WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96-140 pp. (Out of stock.)

WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)

WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. (Out of stock.)

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.

WS 78. Preliminary report on artesian basin in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.

WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.

WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.

WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.

WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls. (Out of stock.)

WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879-1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.

WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.

WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.

WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

WS 149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls.

WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.
WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.
WS 155. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906. 83 pp., 9 pls.
WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.
WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.
PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.
WS 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson, 1906. 86 pp., 6 pls.
PP 53. Geology and water resources of the Bighorn basin, Wyoming, by C. A. Fisher. 1906. 72 pp., 16 pls.
WS 160. Underground-water papers, 1906, by M. L. Fuller. 1906. 104 pp., 1 pl.
WS 163. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp.
WS 164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.
WS 181. Geology and water resources of Owens Valley, California, by Willis T. Lee. 1906. 28 pp. 6 pls.
WS 182. Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 292 pp., 5 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addrest to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

NOVEMBER, 1906.

O

Water-Supply and Irrigation Paper No. 183 Series O, Underground Waters, 63

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

FLOWING WELLS AND MUNICIPAL WATER SUPPLIES

IN THE

MIDDLE AND NORTHERN PORTIONS

OF THE

SOUTHERN PENINSULA OF MICHIGAN

BY

FRANK LEVERETT AND OTHERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

CONTENTS.

	Page.
Introduction, by Frank Leverett	1
Scope of report	1
Geographic features	3
Water-bearing formations	7
Structure of drift	8
Character of drainage	9
Rainfall	10
Ground-water table	11
Wells and appliances	12
Quality of water	14
Subterranean-water temperature	14
Legislation	21
Flowing wells	22
Municipal and institutional water supplies	23
Muskegon County, by C. D. McLouth	25
Topography, by Frank Leverett	25
Water-distributing systems	25
Miscellaneous village supplies	26
Flowing wells	26
General statement	26
White Lake district	27
Muskegon Lake district	31
Lake Harbor district	37
Spring Lake district	39
Moorland district	40
Fruitland district	41
Casnovia district	41
Summary	42
Oceana County, by Myron L. Fuller	46
Topography	46
Flowing wells	46
Flower Creek district	46
Shelby district	49
Hart district	52
Crystal Valley district	53
Elbridge district	54
Tigris district	55
Lattin district	56
Weare district	56
Ferry district	57
Greenwood district	58
Waterworks	59
Hart	59
Shelby	60
Pentwater	60
Miscellaneous village supplies	62

Pages.
Newaygo County, by Myron L. Fuller..... [illegible]
General statement..... [illegible]
Flowing wells..... [illegible]
Hesperia..... [illegible]
Fremont district..... [illegible]
Fremont..... [illegible]
Fremont Lake..... [illegible]
Outlying wells..... [illegible]
Summary..... [illegible]
Newaygo..... 70
Flowing wells..... 70
Waterworks..... 72
Ensley district..... 73
Isolated flows..... 74
Miscellaneous village supplies..... 75
Mecosta County, by Myron L. Fuller..... 75
Topography..... 75
Flowing wells..... 76
Barryton district..... 76
Sheridan Township..... 77
Mecosta..... 78
Paris..... 78
Millbrook..... 78
Town supplies..... 78
Big Rapids..... 78
Miscellaneous..... 79
Mason County, by Myron L. Fuller..... 80
General statement, by Frank Leverett..... 80
Flowing wells..... 80
Bass Lake district..... 80
Waterworks..... 81
Miscellaneous village supplies..... 82
Lake County, by Frank Leverett..... 82
Osceola County, by Myron L. Fuller..... 83
General statement, by Frank Leverett..... 83
Waterworks..... 84
Evart..... 84
Reed City..... 85
Flowing wells..... 85
Evart district..... 85
Reed City..... 87
Marion..... 88
Rose Lake..... 88
Springs..... 88
No-che-mo Springs..... 88
Miscellaneous village supplies..... 90
Quality of water in Oceana, Newaygo, Mecosta, and Osceola counties, by Myron L. Fuller..... 90
Isabella County, by W. M. Gregory..... 92
General statement, by Frank Leverett..... 92
Flowing wells..... 92
General relations..... 92
Coe basin..... 95

Page.

bella County—Continued.
Flowing wells—Continued.
Isabella basin 101
Nottawa basin 105
Isolated flows 108
Mount Pleasant water supplies 109
re County, by Frank Leverett 111
General statement 111
Waterworks 112
Clare 112
Farwell 112
Harrison 112
Miscellaneous town supplies 112
Flowing wells 113
Sheridan Township 113
dwin County, by Frank Leverett 113
General statement 113
Flowing wells 114
Gladwin district 114
McClure district 114
Edwards district 115
y County, by W. F. Cooper 115
Flowing wells 115
Williams Township 115
Kawkawlin Valley 116
Fraser field 117
Pinconning field 117
Mount Forest field 117
Summary 117
Nonflowing wells 118
Quality of water 120
Water temperatures 120
Town supplies 120
Bay City and West Bay City 120
ginaw Bay drainage basin south of Bay and Isabella counties, by Charles A. Davis 121
Introduction 121
Location and boundaries 121
Physiographic features 121
Wells 124
Types 124
Utilization of flowing wells 125
Loss of head 126
Overdevelopment 126
Leaks caused by splitting the casing 127
Leaks caused by rusting of casing 127
Imperfect driving 127
Fine sand and silt 128
Caving at sides 128
Obstructions put in at top of casing 128
Clogging of the strainer on the point 128
Drought in the catchment area 130
Surface drainage 131
Subsurface drainage 131
Quality of water 132

Saginaw Bay drainage basin south of Bay and Isabella counties—Continued. 1
Tuscola County
General statement
Topography and water supply
Lake-plain region
Source of water
Surface waters
Deep-drift waters
Rock waters
Flowing wells
Morainal region
General conditions
Flowing wells
Arbela Township
Fremont and Watertown townships
Wells Township
Valley region
Miscellaneous town supplies
Lake-plain region
Unionville
Akron
Fairgrove
Reese
Ridge region
Gagetown
Kingston
Mayville
Millington
Fostoria
Cass River Valley region
Cass City
Caro
Vassar
Tuscola
Wilmot
Deford
Silverwood
Genesee County
Topography
Public and private supplies
Otisville district
Clio district
Montrose Township
Montrose
Brent Creek
Flushing
Flint Township
Flint
Otterburn
Richfield and Genesee townships
Davison and Burton townships
Davison
Vicinity of Davison
Burton Township
Summary

aw Bay drainage basin south of Bay and Isabella counties—Continued. Page.
enesee County—Continued.
Public and private supplies—Continued.
Gaines and Mundy townships.... 168
Swartz Creek.... 168
Gaines and Mundy area.... 169
Gaines.... 170
Grand Blanc.... 170
Argentine.... 171
Fenton Township.... 171
Linden.... 171
Fenton.... 171
Atlas Township.... 172
Atlas area.... 172
Goodrich.... 172
Atlas-Hadley area.... 173
Livingston County.... 175
Topography.... 175
Supplies by districts.... 176
Howell.... 176
Waterworks.... 176
Flowing wells.... 176
Pinckney area.... 179
Cohoctah area.... 180
Deerfield.... 180
Hartland area.... 181
Shiawassee County.... 183
Topography.... 183
Supplies by districts.... 183
Owosso.... 183
Flowing wells.... 183
Springs.... 185
Waterworks.... 186
Burns Township.... 191
Vernon Township.... 192
Durand.... 192
Vernon.... 192
Corunna.... 193
Saginaw County.... 193
General statement.... 193
Waste water.... 196
Catchment area.... 196
Flowing wells.... 196
Flows from rock.... 196
Flows from drift.... 197
Flows by districts.... 198
Merrill area.... 198
Marion Township.... 198
Brant area.... 198
Fremont Township.... 199
Swan Creek area.... 199
Luce area.... 199
Albee area.... 200
Birch Run area.... 200
Chesaning area.... 200
Thomastown Township.... 200
Saginaw water supply, by A. C. Lane.... 20

Saginaw Bay drainage basin south of Bay and Isabella counties—Continued. P
Gratiot County
General statement
Supplies by districts
Arcada Township
Alma
Vicinity of Alma
Seville Township
Riverdale
Elwell
North of Elwell
Pine River Township
Flowing-well areas
Forest Hill
Bethany Township
St. Louis
Breckenridge
West of Pine River
East of Pine River
Summary
Elbe Township
Bannister
Ashley area
Miscellaneous village supplies
Ithaca
Beebe
Edgewood
Elm Hall
Middleton
Newark and New Haven
North Star
Ola
Perrinton
Pompeii
Rathbone
Wheeler
Midland County
General statement, by Frank Leverett
Supplies by districts
Larkin Township
Midland Township
Midland
Vicinity of Midland
Summary
Ingersoll district
Greendale Township
Jasper Township
Geneva and Warren townships, by W. M. Gregory
Sanilac County, by Frank Leverett
Topography
Waterworks
Brown City
Marlette
Crosswell and Lexington

ac County—Continued. Page.
Waterworks—Continued.
Carsonville 248
Sanilac Center 248
Miscellaneous village supplies 248
Flowing wells 249
Lexington district 249
Buel field 252
Peck district 253
Valley Center area 254
Port Sanilac fields 255
Sanilac Center field 256
Snoover field 256
Argyle Township 257
Minden City field 257
n County, by A. C. Lane 257
General statement 257
Waterworks 259
Harbor Beach 259
Bad Axe 259
Miscellaneous village supplies 260
Supplies by townships 260
Sebewaing 260
Brookfield 262
Grant 262
Sheridan 262
Bingham 263
Paris 263
Sherman 263
Whiterock 263
Sand Beach 263
Sigel 264
Verona 264
Colfax 264
Oliver 264
Winsor 265
Fairhaven 266
Caseville 266
Chandler 266
Meade 267
Lincoln 267
Bloomfield 267
Rubicon 267
Lake 267
Hume 268
Dwight 268
Huron 268
Gore 268
Port Austin 268
hwest border of Saginaw Bay, by W. M. Gregory 269
General statement 269
Waterworks 269
Flowing wells 269
Location 269
Pinconning 270

Northwest border of Saginaw Bay—Continued.
Flowing wells—Continued.
Twining
Tawas
Miscellaneous
Miscellaneous village supplies
Ogemaw County, by W. M. Gregory
General statement, by Frank Leverett
Miscellaneous village supplies
Flowing wells
West Branch area
Rose City area
Manistee County, by Frank Leverett
General statement
Waterworks
Manistee City
Miscellaneous village supplies
Flowing wells
Arcadia
Vicinity of Kaleva
Bear Lake
Onekama, by W. M. Gregory
Wexford County, by Frank Leverett
Missaukee County, by Frank Leverett
Topography
Flowing wells
Dolph district
McBain district
Waterworks
Lake City
Jennings
Miscellaneous village supplies
Roscommon County, by Frank Leverett
Alcona County, by Frank Leverett
Oscoda County, by Frank Leverett
Crawford County, by Frank Leverett
Kalkaska County, by Frank Leverett
Grand Traverse County, by Frank Leverett
General statement
Miscellaneous village supplies
Flowing wells, by W. M. Gregory
Williamsburg area
Traverse City
Benzie County, by Frank Leverett
General statement
Flowing wells
Thompsonville
Honor
Beulah and Benzonia, by W. M. Gregory
Frankfort area, by W. M. Gregory
Waterworks
Frankfort
Thompsonville
Miscellaneous village supplies

Page.
ınaw County, by Frank Leverett 331
im and Charlevoix counties, by Frank Leverett 333
General statement 333
Flowing wells 335
Alden 335
Intermediate Lake district 335
General relations 335
Bellaire 336
Central Lake 337
Summary 338
Norwood 339
East Jordan-South Arm district 339
Ironton 340
Boyne 341
Spring-water siding 343
Boyne Falls 343
Walloon Lake district 343
Waterworks 344
Antrim County 344
Central Lake 344
Elk Rapids 344
Mancelona 344
Miscellaneous 345
Charlevoix County 345
Bay Shore 345
Boyne 345
Charlevoix 346
East Jordan 346
Miscellaneous 346
Otsego County, by Frank Leverett 347
Montmorency County, by Frank Leverett 349
Alpena County, by Frank Leverett 350
Presque Isle County, by Frank Leverett 352
Cheboygan County, by Frank Leverett 353
General statement 353
Springs 354
Waterworks 355
Cheboygan 355
Miscellaneous village supplies 355
Flowing wells, by W. M. Gregory 355
Mullet Lake, by Frank Leverett 355
Haakwood 356
Cheboygan 357
Indian River area 357
Mullet and Burt lakes 363
Emmett County, by Frank Leverett 364
General statement 364
Miscellaneous village supplies 365
Flowing wells 365
Petosky and Bay View 365
Harbor Springs and Wequetonsing areas 366
Crooked Lake area 371
Index ..... 37[illegible]

ILLUSTRATIONS.

		Page.
re I.	Artesian water map of Michigan	6
II.	Geologic map of Michigan	8
III.	Topographic and artesian well map of Bay County	116
IV.	Topographic and artesian well map of the north shore of Saginaw Bay	270
V.	*A*, Large flowing well from rock, Turner, Arenac County; *B*, Fire service test showing five streams from a single well under natural pressure, Arcadia, Manistee County	272
1.	Sketch map showing area covered by report	2
2.	General average of flowing-well temperatures in the Southern Peninsula of Michigan	17
3.	Diagram showing fluctuations in air and well temperatures at Ann Arbor, Mich	19
4.	Sketch map of Flower Creek artesian district, Oceana County	46
5.	Sketch map of Shelby artesian district, Oceana County	49
6.	Diagrammatic section across Shelby artesian district from north to south	51
7.	Sketch map of Hart artesian district, Oceana County	51
8.	Sketch map of Crystal Valley artesian district, Oceana County	54
9.	Sketch map of Elbridge artesian pool, Oceana County	55
10.	Sketch map of Tigris pool, Oceana County	56
11.	Sketch map of Weare pool, Oceana County	57
12.	Sketch map of Ferry district, Oceana County	57
13.	Sketch map showing flowing and adjacent wells, Greenwood district, Oceana County	58
14.	Plat of Hesperia, Newaygo County, showing location of wells and private waterworks	63
15.	Plat of Fremont, Newaygo County, showing location of waterworks and important wells	65
16.	Arrangements at Hain well, Fremont Lake, Newaygo County	67
17.	Map showing location of outlying flowing wells of Fremont district	69
18.	Plat of Newaygo, showing location of waterworks, mains, and flowing wells	70
19.	Location of Ensley flowing wells, Newaygo County, in relation to local drainage	73
20.	Sketch map of Barryton artesian district, Mecosta County	76
21.	Sketch map of Bass Lake artesian district, Mason County	80
22.	Sketch map of Evart artesian district, Osceola County	86
23.	Profile of water beds and surface in Isabella County	92
24.	Sketch showing fluctuations of Abbott's well, 2 miles north of Shepherd, Coe Township, Isabella County	94
25.	The Coe flowing-well district of Isabella and Midland counties	95
26.	Cross section from Isabella to Denver Township	101
27.	Relation of wells near Dover, Clare County	106
28.	The Nottawa flowing-well district in Isabella and Clare counties, and the Isabella flowing-well district in Isabella County	107

Page.
FIG. 29. Sketch map of Montrose flowing-well area, Genesee County 157
30. Sketch map showing valley in which flowing wells occur in Genesee and Richfield townships, Genesee County 160
31. Sketch map showing flowing-well district in Davison and Burton townships, Genesee County 162
32. Diagram showing probable relationship of the water beds across sections 10 and 11, Davison Township 162
33 Plat showing distribution of flowing wells in Davison village, Genesee County 163
34. Map showing flowing wells in the Gaines-Mundy area, Genesee County 169
35. Sketch map of the Ortonville, Hadley-Atlas, Groveland, and Atlas flowing-well areas 174
36. Plat of portion of Howell, Livingston County, showing flowing-well district. 177
37. Sketch map of Cohoctah flowing-well area, Livingston County 180
38. Sketch map of Hartland area, Livingston County, showing location of wells. 182
39. Sketch map of Maple Ridge Park and vicinity, Owosso, showing approximate location of flowing wells 184
40. Distribution of wells at Owosso waterworks, on a terrace of Shiawassee River, 5 feet above low-water level 186
41. Sketch map showing location of flowing wells in Burns Township, Shiawassee County 191
42 Plat of Alma, showing distribution of flowing wells 205
43. Sketch map of flowing-well district in areas 1 and 2, Pine River Township, Gratiot County 215
44. Sketch map showing approximate position of the flowing wells in areas 3 and 4, Pine River Township, Gratiot County 216
45. Bethany Township flowing-well areas, Gratiot County 221
46. Plat of village of Bannister, Gratiot County 224
47. Ashley and Bannister flowing-well areas outside of village wells 227
48. Sketch map of Larkin flowing-well district, Midland County 233
49. Map showing distribution of flowing wells in and near Midland 236
50. Map of Greendale Township flowing-well area, Midland County 243
51. Map of Lexington, Sanilac County, showing flowing wells and neighboring springs 250
52. Contour map showing the elevation of the top of the upper Marshall sandstone above sea level 258
53. Cross section from Bayport quarries southwest, showing the relations of present surface, rock surface, flowing wells, etc 259
54. Map of Pinconning, Bay County, showing distribution of flowing wells... 270
55. Map of Twining, Arenac County, showing distribution of flowing wells 272
56. Map of Tawas flowing-well district, Iosco County 275
57. Map of West Branch, Ogemaw County, showing flowing wells 283
58. Map of Rose City showing location of flowing wells 289
59. Ideal section showing distribution of water beds 290
60. Flowing wells in and near Onekama, Manistee County 297
61. Contour map of Williamsburg flowing-well district 316
62. East-west section through Williamsburg district 317
63. North-south section through Williamsburg district 318
64. Map of southeast end of Crystal Lake, Benzie County 327
65. Contour map of Indian River flowing-well district 358
66. Contour map of Harbor Springs flowing-well district 367
67. Sketch map of flowing-well region between Conway and Indian River.... 371
68. Contour map of Oden and vicinity 372
69. North-south section at Oden, showing water beds 373

LOWING WELLS AND MUNICIPAL WATER SUPPLIES IN THE MIDDLE AND NORTHERN PORTIONS OF THE SOUTHERN PENINSULA OF MICHIGAN.

By Frank Leverett and others.

INTRODUCTION.

By Frank Leverett.

SCOPE OF REPORT.

A large amount of data on water supplies was collected by the writer in the course of glacial investigations made under the direction of Prof. T. C. Chamberlin in the last five years in the Southern Peninsula of Michigan. These investigations resulted in a partial acquaintance with conditions in about 200 separate flowing-well districts and brought out matters of such exceptional importance that arrangements were made to extend them by examining each of the flowing-well districts in the State sufficiently to determine its essential characteristics, present state of development, and probable capacity for future development. It was arranged also that the quality of various classes of water, both surface and underground, as well as water supplies of cities and villages, should be given attention. As the mineral waters of the State had already been discussed in some detail by the State geologist, Dr. A. C. Lane, in Water-Supply Paper No. 31 of the United States Geological Survey, it was deemed unnecessary to prepare another report on that subject, but arrangements were made with Doctor Lane for embodying in this report the large amount of material which had accumulated at his office relative to other classes of water supply, and also for furnishing reports on certain counties in which special investigations had been carried on by the State survey. The results of all these studies, so far as they apply to the middle and northern counties (see fig. 1, on next page), are embodied in the present report; the remainder appears in a companion report on the southern counties of the Southern Peninsula of Michigan.

In completing the necessary field work for this report several persons were employed for a short time and were assigned to separate

districts, as follows: Jon Andreas Udden, of Rock Island, Ill., was employed from July to December, 1904, in an investigation of the southern counties, chiefly those south of Kalamazoo River, and parts of Macomb and Oakland counties in the eastern part of the State. Mr. Isaiah Bowman, of Yale University, was engaged for six weeks in August and September, chiefly in the region tributary to Grand River.

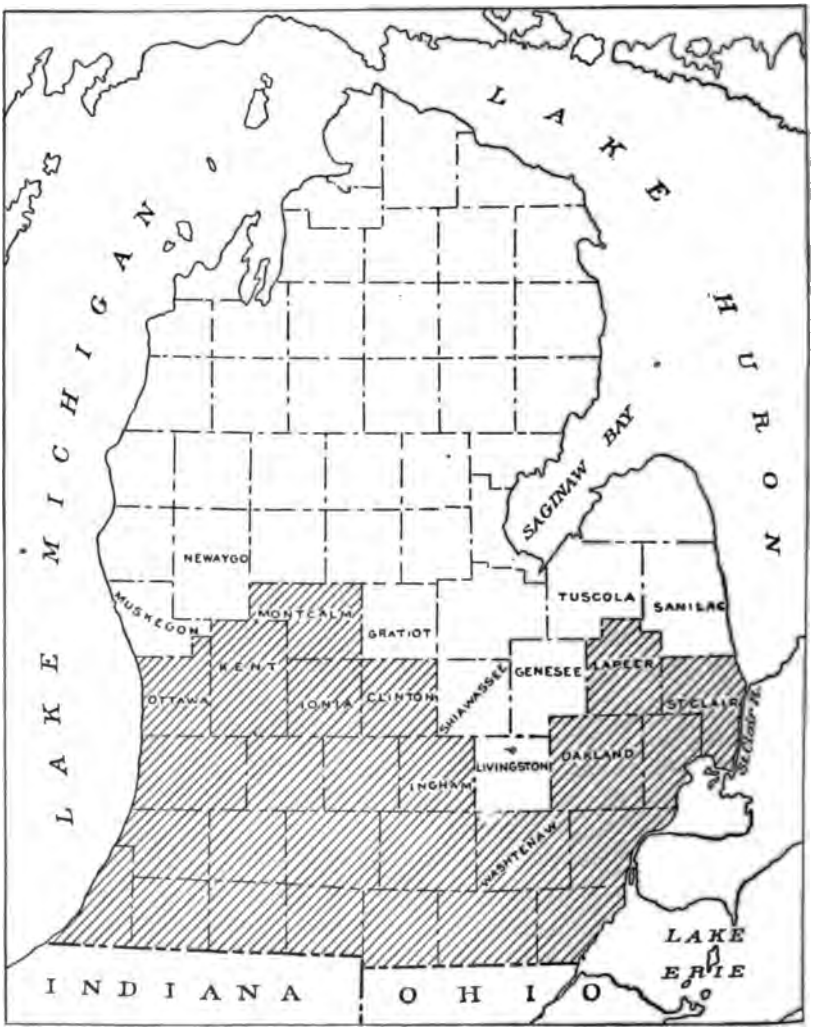


FIG. 1.—Sketch map, showing area covered by report. The ruled area is discussed in Water-Supply Paper No. 182.

Prof. C. A. Davis, of the University of Michigan, was employed during July, August, and September in the investigations of the southern and eastern portions of the basin of Saginaw River. Mr. W. M. Gregory, of the department of physiography in the Cleveland, Ohio, high school, was employed during July, August, and part of September

the investigation of the northwestern portion of the Saginaw River asin, and also of flowing-well districts in the northern part of the eninsula, in Cheboygan, Emmett, Grand Traverse, Benzie, and anistee counties, to which he had previously given some attention in onnection with stream measurements under Mr. Robert E. Horton. Ir. M. L. Fuller, of the Geological Survey, under whose direction the ork was carried on, visited several of the men in the field and spent ugust and part of September in an investigation of the deficiency of ater supplies along the Huron River Valley near Detroit, and in a etailed study of the flowing wells in four western counties, Oceana, ewaygo, Mecosta, and Osceola. Muskegon County was investiated by Mr. C. D. McLouth, of the department of physics of the Iuskegon high school; Kent County, by Mr. J. F. Nellist, a civil ngineer of Grand Rapids; Bay County, by Mr. W. F. Cooper, of the tate Geological Survey; and Wayne County, by Prof. W. H. Sherzer, f the State normal college at Ypsilanti, who also furnished the data or the report on Monroe County. Doctor Lane, the State geologist, nvestigated and reported on conditions in the vicinity of Lansing and lso prepared a brief report on Huron County, condensed from his ore elaborate State report. The present writer's investigations uring the last season were chiefly in Sanilac, Lapeer, and St. Clair ounties on the eastern border of the State, and in Charlevoix, Antrim, nd Benzie counties in the northwestern part. Mr. S. J. Lewis, of the Inited States Geological Survey, was detailed for a special investigaion of the quality of waters and spent about a month in the State, n January and February, 1905, during which time he made about 0 analyses. Dr. V. C. Vaughan, dean of the medical school of the Iniversity of Michigan, kindly placed at the disposal of the Survey a arge number of analyses made for sanitary purposes, but including leterminations of hardness, chlorides, and sulphates. Field analyses vere also made by Messrs. Fuller, Gregory, and Bowman, which will e found in connection with their reports herewith presented. Reports vere submitted by all those engaged in this investigation with the xception of Mr. Udden, who merely turned in his tabulated data and otebooks. Much work, however, was necessary in order to bring the everal reports to a more nearly uniform standard, and the present vriter has amplified portions, inserted additional data at many points, nd supplied most of the geologic and other general descriptions. he several reports, however, naturally differ somewhat in mode of reatment, according to the personal standards of the individual writers.

GEOGRAPHIC FEATURES.

The Southern Peninsula of Michigan is bordered on its entire westrn coast by Lake Michigan, on the north by the Straits of Mackinac, nd on the east, from north to south, by Lake Huron, St. Clair River,

districts, as follows: Jon Andreas Udden, of Rock Island, I employed from July to December, 1904, in an investigation southern counties, chiefly those south of Kalamazoo River, an of Macomb and Oakland counties in the eastern part of the Mr. Isaiah Bowman, of Yale University, was engaged for six w August and September, chiefly in the region tributary to Grand

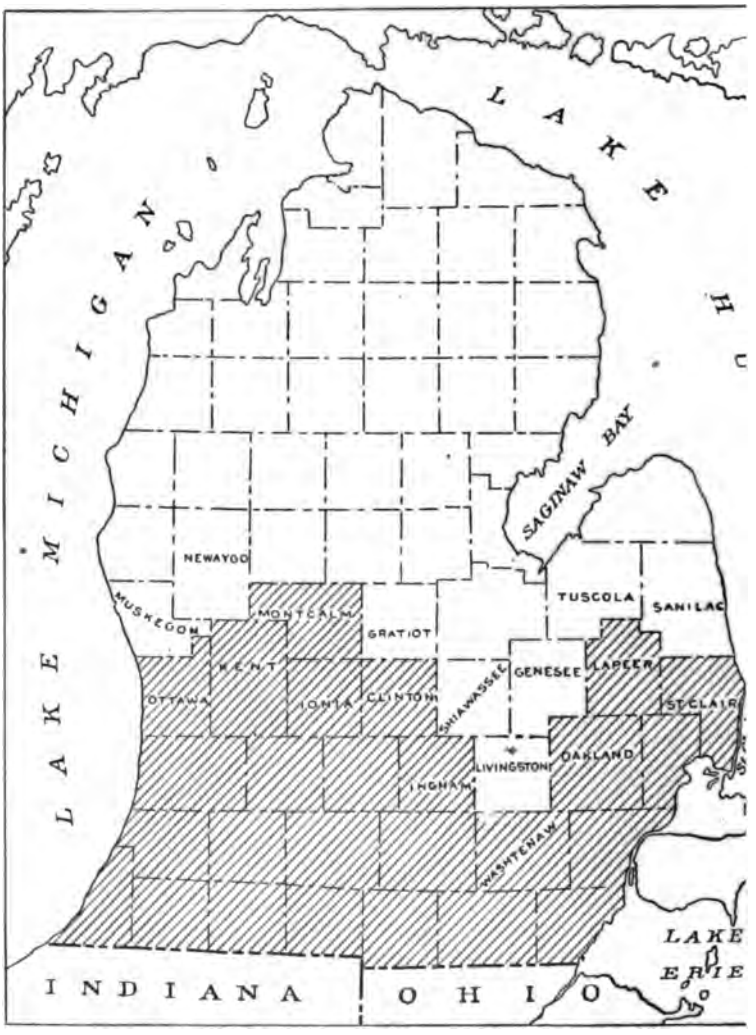


FIG. 1.—Sketch map, showing area covered by report. The ruled area is discussed in Wat Paper No. 182.

Prof. C. A. Davis, of the University of Michigan, was employed July, August, and September in the investigations of the sc and eastern portions of the basin of Saginaw River. Mr. Gregory, of the department of physiography in the Cleveland high school, was employed during July, August, and part of Sep

the investigation of the northwestern portion of the Saginaw River sin, and also of flowing-well districts in the northern part of the ninsula, in Cheboygan, Emmett, Grand Traverse, Benzie, and anistee counties, to which he had previously given some attention in nnection with stream measurements under Mr. Robert E. Horton. r. M. L. Fuller, of the Geological Survey, under whose direction the ork was carried on, visited several of the men in the field and spent ugust and part of September in an investigation of the deficiency of ater supplies along the Huron River Valley near Detroit, and in a etailed study of the flowing wells in four western counties, Oceana, ewaygo, Mecosta, and Osceola. Muskegon County was investiated by Mr. C. D. McLouth, of the department of physics of the luskegon high school; Kent County, by Mr. J. F. Nellist, a civil ngineer of Grand Rapids; Bay County, by Mr. W. F. Cooper, of the tate Geological Survey; and Wayne County, by Prof. W. H. Sherzer, f the State normal college at Ypsilanti, who also furnished the data or the report on Monroe County. Doctor Lane, the State geologist, nvestigated and reported on conditions in the vicinity of Lansing and lso prepared a brief report on Huron County, condensed from his more elaborate State report. The present writer's investigations during the last season were chiefly in Sanilac, Lapeer, and St. Clair counties on the eastern border of the State, and in Charlevoix, Antrim, and Benzie counties in the northwestern part. Mr. S. J. Lewis, of the United States Geological Survey, was detailed for a special investigation of the quality of waters and spent about a month in the State, in January and February, 1905, during which time he made about 90 analyses. Dr. V. C. Vaughan, dean of the medical school of the University of Michigan, kindly placed at the disposal of the Survey a large number of analyses made for sanitary purposes, but including determinations of hardness, chlorides, and sulphates. Field analyses were also made by Messrs. Fuller, Gregory, and Bowman, which will be found in connection with their reports herewith presented. Reports were submitted by all those engaged in this investigation with the exception of Mr. Udden, who merely turned in his tabulated data and notebooks. Much work, however, was necessary in order to bring the several reports to a more nearly uniform standard, and the present writer has amplified portions, inserted additional data at many points, and supplied most of the geologic and other general descriptions. The several reports, however, naturally differ somewhat in mode of treatment, according to the personal standards of the individual writers.

GEOGRAPHIC FEATURES.

The Southern Peninsula of Michigan is bordered on its entire western coast by Lake Michigan, on the north by the Straits of Mackinac, and on the east, from north to south, by Lake Huron, St. Clair River,

to which attention is directed in the discussion of Antrim and Charle counties, in which it appears (pp. 333–335).

The features of the State thus briefly outlined receive fuller t ment in connection with the discussion of each county.

On the retreat of the ice from the basins bordering and inclu the Great Lakes large bodies of water were held between the ice the rims of these basins. One, in the Lake Michigan basin, known as Lake Chicago and discharged southwest from the site of city to Illinois River. Another, in the Saginaw basin, was know Lake Saginaw and discharged westward through Grand River Lake Chicago. A third, covering the western end of Lake Erie the southern part of Lake Huron, stood at several successive lev accordance with the lowest available outlet, the highest being k as Lake Maumee with its outlet past Fort Wayne to the Wabash later past the present site of Imlay, Mich., westward into Grand and Lake Chicago. Below this is the largest shore line of the s known as the Belmore beach, which borders Lake Whittlesey, w outlet was westward from the present site of Ubly, Mich., into Saginaw. A little lower than the Belmore beach is the Arkona, w antedates the Belmore and was submerged at the time the Bel was forming. The lake which formed the Arkona beach was ably confluent with Lake Saginaw and discharged westward thr Grand River to Lake Chicago. Two lower beaches, known a Upper Forest and the Lower Forest, mark the border of Lake Wa which covered the Saginaw and southern part of the Huron bas well as Lake Erie, and discharged westward, for a time at through Grand River to Lake Chicago. Below the Forest beache two others, known as the Grasmere and Elkton, which appear the shores of a lake that discharged eastward past Syracuse, N. Y Mohawk and Hudson rivers. At still lower levels are beaches are conspicuous on the borders of the Lake Huron and Lake Mich basins, especially in the vicinity of the Straits of Mackinac. O known as the Algonquin beach; Lake Algonquin, which forme discharged along the present line of drainage through Lake Erie t Ontario basin into a Glacial lake known as Lake Iroquois, whose let was through the Mohawk and Hudson. A lower beach, know the Nipissing beach, borders a post-Glacial lake, Lake Nipissing, was formed as the lake was changing from a discharge eastward Georgian Bay through Mattawa and Ottawa rivers into the St. L rence to the present line of discharge through St. Clair River.

The sand and gravel in these beach ridges and on the lake beds quently serve as sources of supply in shallow wells, water being fo at the base of the sand or gravel.

WATER-BEARING FORMATIONS.

The greater part of the Southern Peninsula is covered so deeply with drift that wells do not reach rock. The shaded portions of the map, Pl. I, show the parts of the State where rock is within easy reach of the drill and is drawn upon to some extent for drinking water. In the northern end of the peninsula water is found chiefly in limestone if not in the drift. There is also a limestone district in the southeastern part that serves extensively as a source for drinking water; in some cases in southeastern Lenawee County the wells are driven through shale to reach the limestone. The extensive district running from Hillsdale and Calhoun counties northeastward to Saginaw Bay obtains water chiefly from sandstones of the coal measures and from the Marshall sandstone, if water is not found in the drift. There are, however, small limestone districts in this region the full extent of which have not been worked out. Sandstone is also drawn upon occasionally in western Wayne, southern Washtenaw, and northern Lenawee counties in the deep flowing wells. The Sylvania sandstone of Monroe County is also an important water bearer, yielding a good quality of water. There are small areas around Grand Rapids—in Kent and eastern Ottawa counties—and around Wayland, in northeastern Allegan County, where wells are driven to the Marshall sandstone.

Water is found in the glacial formations at various horizons, wherever gravel or sand chance to be present. The clay plains bordering St. Clair River, Lake St. Clair, and Detroit River are deficient in gravel and sand, and are perhaps the poorest water bearers in the peninsula. As a rule, water in large quantities is easily obtained in the drift. Even in the regions where wells are driven to rock, as indicated by the shaded portions of Pl. I, there are numerous wells obtaining water from the glacial deposits. The water from rock is usually softer in sandstone areas than that from the overlying drift, and for that reason is preferred and is the cause for going to the rock in many instances.

The sand along the present shore, and also along abandoned shores of the Great Lakes, is often of sufficient depth to furnish water, though not that of the best quality in many cases. It so happens that these sand deposits occur on parts of the lake plain where the glacial formations are deficient in water-bearing beds and thus become of great importance locally. In general, however, the water from the underlying glacial formations is preferred and is used wherever it can be easily obtained.

The newest formations drawn upon for water are the beds of bog lime bordering the little lakes. Pipes are driven down into the marl sometimes with a sledge hammer far enough to get the water. In some cases, in the northern part of the State, flowing wells have been

obtained by penetrating the marl a few feet. Conspicuous insta are found on the borders of Pine Lake at East Jordan, South and Boyne, and on the borders of Intermediate Lake near Bellai

STRUCTURE OF DRIFT.

The structure of the drift is intimately related to the drainage ditions that attended the melting of the ice. It is more variab Michigan, both on the surface and below, than in a large part o neighboring States of Ohio, Indiana, and Illinois. In those State till or commingled drift greatly predominates over the sand and g or assorted drift and contains a large percentage of fine clayey m rial. In Michigan, sand and gravel form a large part of the drift, much of the till is loose textured. The great amount of loose-text drift seems attributable to the voluminous discharge of water resu from the convergence of ice lobes. It is best developed on the portions of the State, which were built up between the ice lobes. most clayey portion of the drift is found in plains bordering the basins. On these plains more difficulty is found in obtaining adeq supplies of water than in the higher tracts bordering them. Por of the plains have a thin coating of sand deposited in the beds o Glacial lakes that covered them after the withdrawal of the ice, a these localities many wells draw their supply from the surface sa

Flowing wells are usually found under a bed of clayey drift, an this reason, as well as because of topographic conditions, the la artesian districts are found on the old lake plain.

The clayey drift differs greatly in degree of induration at diffe horizons, and the sand and gravel also become cemented at ce horizons. The induration in the clay or till seems to be largely a r of secondary changes produced slowly, and is in some cases an ind age. The surface-till sheet, which is of the Wisconsin stage, is erally a soft, adhesive clay, even where very fine textured, and well gers and drillers find very little difficulty in penetrating it. Below the drift is found to be extensively indurated, so that excavati difficult, and the till approaches a shale in its resistance. The pr nature of the induration has not been ascertained. It is thought much of this indurated clayey drift was deposited in a Glacial s earlier than the one that formed the upper part of the drift—prob the Illinoian stage. In some places a soil appears between the sheets of till, showing that an interval separates them. The b soils are much more abundant in northern Indiana than in sout Michigan, but they have been noted in well borings as far north as and Oceana counties.

Another kind of induration of the drift is very common in flo well districts. Just above the water bed which yields the fl found a cemented crust, having a thickness usually of only a few in

This crust is apparently due to contact with the water, but the precise chemical or physical changes that have produced it have not been given much attention. In some cases it has the appearance of bog-iron ore and in others it is chiefly carbonate of lime. Probably the quality of the water determines the nature of the crust. A crust has also been frequently noted in sand and gravel deposits just above the water table, where it is somewhat constant at a definite horizon.

It is a common experience to find sand so close textured that it will not furnish water fast enough to supply the wells. Such sand is encountered in the plains, perhaps, more frequently than in the rolling or morainic belts. It is the custom in such places to continue the drilling to a looser textured bed, though in some localities no such bed is found. If a looser textured bed is reached, the water often rises in the pipe to a higher level than in the overlying sand, the sand apparently serving as a cover to prevent the upward escape of water from the porous bed. In a few places flowing wells have been obtained in which nothing but sand was penetrated from the surface down to the coarser bed that yielded the flow.

CHARACTER OF DRAINAGE.

The character of the drainage depends on the structure of the drift, as well as on the topography. Where the soil is very loose textured, as on gravel plains and on many of the larger moraines, very little surface run-off occurs, so that even the steep hillsides show little or no gullying. Basins are numerous on the gravel plains and to some extent along the moraines. When of sufficient depth to extend below the water table, they contain water, but a large proportion of them are so shallow as to have dry bottoms. The drainage lines are therefore best developed in the clayey portions of the State, where the rainfall can not be quickly absorbed by the soil.

The regimen of the stream varies also in accordance with the structure of the drift. Where the drift is loose textured, the streams are supplied by seepage from the underground drainage and are not subject to freshets nor to very low stages, but in the clayey tracts, where the surface drainage is the principal factor, there is a marked difference between the high- and low-water stages of the streams. Often, however, the sources of the streams are in districts having a loose-textured drift, while the lower courses run through clayey districts. In such cases the streams have a correspondingly regular flow. Data concerning the flow of the principal streams of the peninsula may be found in the reports on stream measurements, which appear in the water-supply series of the United States Geological Survey. The regularity of flow, as well as the considerable fall of the principal streams of the peninsula,

renders them valuable for water power to an exceptional degree, considering the small size of their drainage basins. The subject of water power, however, is not taken up in the present report.

RAINFALL.

From the reports of the Weather Bureau it appears that the rainfall is greatest in the southern tier of counties and decreases northward to a little beyond the middle of the peninsula, where a change occurs toward heavier precipitation. This is set forth in the following table, which gives the average precipitation by tiers of counties from south to north, each tier having a uniform width of 24 miles:

Average annual precipitation in the Southern Peninsula of Michigan.

	Inches.
First or southern tier (Monroe to Berrien County)	34.59
Second tier (Wayne to Van Buren County)	31.99
Third tier (Macomb to Allegan County)	30.81
Fourth tier (St. Clair to Ottawa County)	31.19
Fifth tier (Sanilac to Muskegon County)	30.66
Sixth tier (Bay to Oceana County)	27.21
Seventh tier (Arenac to Mason County)	25.44
Eighth tier (Iosco to Manistee County)	26.62
Ninth tier (Alcona to Benzie County)	33.64
Tenth tier (Alpena to Leelanau County)	32.53
Eleventh tier (Presque Isle to Charlevoix County)	28.07
Twelfth tier (northern Cheboygan and Emmett counties)	31.41
Average for the peninsula	30.30

The distribution of precipitation by months and the percentages by seasons in the southern, central, and northern sections of the peninsula are given in the following tables, which are based on the monthly rainfall data of the Weather Bureau:

Average monthly rainfall in the Southern Peninsula of Michigan.

[Inches.]

Month.	Southern third.	Central third.	Northern third.
January	2.33	1.96	2.43
February	2.31	2.16	1.60
March	2.68	3.09	2.30
April	2.34	2.16	1.86
May	3.68	2.73	2.70
June	3.54	3.00	2.80
July	3.43	2.96	4.47
August	2.64	2.58	2.08
September	2.76	2.98	3.41
October	2.48	2.40	3.10
November	2.82	2.44	2.38
December	2.47	1.53	1.60

Distribution of precipitation in the Southern Peninsula of Michigan by seasons.

[Per cent.]

Season.	Southern third.	Central third.	Northern third.	Entire peninsula.
Winter (December to February)	21.23	18.73	18.40	19.45
Spring (March to May)	26.00	26.43	22.15	24.86
Summer (June to August)	28.70	28.28	30.63	29.20
Autumn (September to November)	24.07	26.56	28.82	26.48
	100.00	100.00	100.00	99.99

It appears from the above tables that the rainfall is most deficient in the winter months at a time when the frozen ground would prevent its absorption, but is well distributed throughout the growing season all over the peninsula. It should be noted that the greater evaporation in the southern part of the peninsula causes it to be a drier region than the northern part, notwithstanding the fact that it has a little more rain. Determinations made at signal-service stations, and discussed by T. Russell in the Monthly Weather Review for September, 1888, show that the evaporation near the southern border of the State is 37 to 38 inches a year, while in the latitude of Port Huron and Grand Haven it is about 29 inches, and at Alpena 24.3 inches. Only a small part of the evaporation occurs in the winter months or during the time of deficient precipitation, so the deficiency is not noticeable. Indeed, as a rule snow remains continuously over much of the peninsula from December to March.

GROUND-WATER TABLE.

The ground-water table as ordinarily understood marks a level to which the saturation of the earth's crust rises. In a region of heavy rainfall it is commonly very near the surface, but in arid regions it may lie at a considerable depth and is sometimes beyond the general direct percolation of the rainfall, there being a moist layer at the surface supplied by the rainfall under which the material is dry down to the ground-water table. Ordinarily the ground-water table in the Southern Peninsula of Michigan lies only a few feet below the surface, within easy reach of the roots of trees and other plants. A few places, however, have been revealed by well borings in which comparatively dry material is present between the moist surface beds and the ground-water table. The most conspicuous instance is found in Emmett County north of Little Traverse Bay, where the wells on an elevated table-land underlain by gravel and sand reach depths of 350 to 400 feet before striking the water table; instances of this are cited in the discussion of the county (p. 364). The rainfall in that region appears to moisten chiefly the surface portion, but is yet adequate to the needs of the forests, orchards, and crops. On many of the elevated gravel plains the water table is 40 to 60 feet, and

occasionally 100 feet below the surface, and wells must be driven to these depths to obtain water, and yet vegetation ordinarily thrives on these plains. Similar conditions are found in a number of the prominent moraines, in which a sheet of bowldery till at the surface is underlain by sand and gravel of considerable depth. The till at the surface is kept moist by the rainfall, so that the crops obtain the necessary water. In all these localities there are probably places where conditions are such that the rainfall percolates directly down to the water table, but there does not appear to be a general percolation to this depth.

Where the ground-water table lies only a few feet below the surface and the percolation of the rainfall to it is general, marked fluctuation are found in its level corresponding with the amount of rainfall. Th underground drainage into the streams is maintained in times c drought as well as in wet seasons, and the water table drops down o flattens out beneath the hills to depths sufficient to seriously affec not only the crops but the supply for wells. As a result the so-calle surface wells (which are merely basins sunk into the upper part of th ground-water table) are being rapidly abandoned and driven well reaching to deeper supplies substituted. This condition is also con ducive to health, for many of these shallow or surface wells are recep tacles for all sorts of filth.

There is a slight variation in the ground-water table due to barc metric changes, the level of water in the open wells being highest i times of low barometer or just before a storm. It is barometri fluctuation of this sort which produces the blowing wells reported a various points in the State. According to the testimony of we owners the barometric conditions also affect flowing wells, an increas in the rate of flow resulting from a decrease in atmospheric pressur

An instance of remarkably high water table is found in the dune along the shore of Lake Michigan, where a fine or uniform texture sand in sharp ridges with a height of 200 feet above the lake is foun to be wet to within a very few feet of the surface. Because of th condition some of the dunes are covered with hardwood forests.

WELLS AND APPLIANCES.

One of the most common types of well is the large open or dug we walled or curbed, which furnishes a basin in which the water colle or stands. This kind of well is in very common use on the farms, a is also in use as a collecting reservoir in the villages for the waterwo supply. In districts where the drift is of a clayey texture and t yield of water is small, these large wells serve a valuable purpose collecting basins, and in many cases can not be dispensed with ev though known to be more or less subject to surface contamination.

A type in use locally, especially in clayey districts, is known as the bored well, the excavation being made by means of a large auger. These wells are usually lined with tile. They can be sunk without difficulty to depths of 50 to 100 feet. Some of the oldest flowing wells in southeastern Michigan are of this type.

A type which is coming into very general use throughout the State is known as the tubular well. It is made with the ordinary churn drill, the material being brought up by means of a sand pump. The size of these wells ranges from 2 inches or less to about 8 inches. They are in very common use in the villages for obtaining public water supplies, as well as throughout the country districts. Ordinarily they are driven some distance into the water bed, making up in vertical direction for the small diameter of the well, no casing being used after entering the water bed. Where flowing wells are obtained, however, it is customary to stop the drilling about as soon as the water bed is reached. The drills used in making wells of this type are usually handled by steam or horsepower, but in some instances only hand power is used, the drill being lifted by a windlass a few feet and dropped into the hole.

In some cases no drill is used, but the pipe is driven to the water bed, the material being removed by a sand pump if the well is deep or if it has a large-sized pipe. Shallow wells with small pipe are often driven through to the water bed without sand pumping. It is common to attach a sharp perforated cone or "point" to admit the water, which aids in reducing the resistance to driving the pipe. In some cases these wells are made by simply using a maul to drive the pipe.

In the discussion by Mr. Davis attention is directed to strainers or screens, which are employed in the tubular wells, and to the clogging which they experience (pp. 128–130).

Windmills are in very common use throughout the State as a means for lifting the water to the surface. In some of the deeper wells on elevated tracts the windmill has become a necessity, for the water in some instances has to be lifted about 200 feet—one case was found in which the lift was 400 feet. In this well a 12-foot wheel was in use.

Many flowing wells are allowed to discharge the water without restriction, but there is a growing sentiment in favor of using reducers or faucets to prevent waste.[a] In some cases pumps have been attached in order to prevent the slop attending the flow or, where the wells are weak, to increase the supply.

[a] For State laws on this point see p. 21.

QUALITY OF WATER.

The chemical character of the water, both surface and underground, has been considered at some length by Doctor Lane in Water-Supply Paper No. 31, where numerous analyses are presented. The present report contains many additional analyses, some of them made by chemists in the laboratory and some by men in the field. Although the latter are designed to show the general characteristics of the waters, without pretense to the accuracy of a laboratory analyses, the results are usually correct within a few parts per million.

In general, the waters from all horizons, both surface and underground, in the Southern Peninsula are hard compared with waters found in regions in which readily soluble rocks, like limestone and gypsum, are not present. There are very few waters in which the carbonate of lime is less than 50 parts per million.

Salt is present in varying amounts, from a mere trace up to several thousand parts in a million. An analysis of one water from the drift made by Mr. Lewis shows 2,829 parts per million of chlorine, the well being supplied presumably from water contributed to the drift from the underlying sandstone. Ordinarily the drift waters show less than 25 parts per million.

Sulphated and sulphureted waters are found at various points in the State, both in the drift and in the underlying rock, but ordinarily the drift waters have very small amounts of sulphureted hydrogen gas and sulphates seem to be principally in the portions of the State where gypsum forms a conspicuous ingredient in the drift, as in the region bordering Saginaw Bay, and reached by the Saginaw glacial lobe and in the region near the gypsum outcrops around Grand Rapids.

Iron is commonly supposed to be present in large amount in the flowing wells, and in wells of similar character whose waters are confined below impervious beds. In some cases its presence is proved by the staining of objects over which the water passes, but in many instances what seems an abundant iron-oxide precipitate is in the main a vegetable growth of algæ. The few available analyses indicate that the amount of iron is small compared with other mineral constituents.

SUBTERRANEAN-WATER TEMPERATURE.

Considerable attention has been given to the temperature of the water in flowing wells in order to obtain information concerning the heat gradients due to depth and to latitude. It was found, however, that the temperatures obtained are of very little value in showing the increase of heat with depth, for as a rule wells in a given district having variations of 100 or even 200 feet in depth, if in the glacial deposits, are very similar in temperature. The circulation of subterranean

rs appears, therefore, to be such that little value can be deter-
d concerning the heat gradient within 200 feet of the surface.
ıe change in temperature corresponding to the latitude, how-
, is very marked, there being a difference of about 5.5° in about
: latitude between the northern and southern ends of the penin-
The air temperature shows a similar range, but averages about
wer than the water temeprature. The true temperature of the
r at the bottom of a well can be obtained only in wells of rapid
having but little exposure of pipe. Nor can the pipe be carried
zontally through the soil without affecting the temperature. It
not possible in the hasty examinations in the field to determine
causes of variation from the bottom temperature in any given
, since this would necessitate much inquiry into all the surround-
conditions. As a result many of the temperatures given in the
ıerous tables of data concerning flowing-well districts are liable
e misleading.
ıteresting variations in temperature of the wells of a given lati-
suggest several problems. For example, wells in swamps are
rally a little cooler than wells of similar depth on the dry land,
cially if the wells are comparatively shallow in both cases. Thus
wells in the celery swamp south of Ann Arbor have a tempera-
of a little less than 50° F., while those on the dry land in the
nity are commonly 51°. The question arises whether the evap-
ion from a swamp, being greater than that from the dry land,
not prevent the heating of the soil beneath to the degree experi-
d in that region on ground where evaporation is less; also whether
slow heat conductivity in a swamp may not cause waters beneath
have exceptionally low temperature.
he flowing-well district in southeastern Oakland County known
he Troy district has salt water in its eastern portion and fresh
r in its western portion from wells of similar depth, and the tem-
ture of the salt water averages somewhat lower than that of the
ı water. The salt water probably comes up from the underlying
, and one would naturally expect it to be warmer instead of colder
ı water supplied entirely from the drift.
he observations on temperature were made in 1904, when the air
perature was considerably below the normal, the average tempera-
for the year being 2.7° below the normal throughout the penin-
. This raises the question whether flowing wells of moderate
th may not have suffered a slight lowering of temperature because
his deficiency in heat received by the surface. On the whole
ing wells less than 30 feet in depth are found to present a slightly
r temperature than do wells exceeding that depth, but there are
any exceptions that some doubt is felt as to the lowering effect
he low air temperature of 1904 on even the shallowest of the

flowing wells. Some of the very shallow flowing wells may, however, receive contributions of water from considerable depths, from beyond the influence of the low air temperature. In the city of Ann Arbor there are springs having a uniform temperature of 51° throughout the year which must come from depths sufficiently low to have been unaffected by the low temperature of 1904, or even by the winter severity of cold.

There are certain districts in which the temperature is different from what would be expected for that part of the State, a conspicuous case being the wells in the vicinity of Grand Traverse Bay, in Antrim and Grand Traverse counties, the temperature of which is generally 48° to 50,° whereas about 47° is to be expected. The high temperature at Traverse City may be referable to the great depth of the wells, the general depth being over 300 feet, but this would not apply to the shallow wells at Williamsburg and around Intermediate Lake. There is, however, a possibility that these shallow wells are supplied by water rising from considerable depths.

The observations on temperatures were taken by several thermometers which have not as yet been standardized. They were, however, compared by tests made on the same wells at Ann Arbor and found to agree within a fraction of a degree. Errors from this source are not likely, therefore, to be appreciable.

In the table below the general averages of air and water temperatures are presented for each tier of counties, as in the rainfall table already given, the counties being of the uniform width of 24 miles. The excess of the water temperature above the air temperature is probably in large part due to the blanketing effect of snow, which prevents the earth from reaching the low temperature which the severity of winter might otherwise give it. The extent to which this and other factors, such as the topography, the character of the soil, etc., apply, is a matter difficult of determination.

General averages of air and water temperatures in the Southern Peninsula of Michigan.

[Degrees F.]

	Air.	Water.	Excess of water temperature.
First or southern tier (Monroe to Berrien County)	48.25	52.25	4
Second tier (Wayne to Van Buren County)	48.1	51.3	3.[illegible]
Third tier (Macomb to Allegan County)	47.0	50.3	3.[illegible]
Fourth tier (St. Clair to Ottawa County)	46.4	50.1	3.[illegible]
Fifth tier (Sanilac to Muskegon County)	46.5	49.4	2.[illegible]
Sixth tier (Bay to Oceana County)	45.5	48.9	3.[illegible]
Seventh tier (Arenac to Mason County)	44.5	48.1	3.[illegible]
Eighth tier (Iosco to Manistee County)	43.4	47.7	4.[illegible]
Ninth tier (Alcona to Benzie County)	43.6	47.8	4.[illegible]
Tenth tier (Alpena to Leelanau County)	41.3	47.2	5.[illegible]
Eleventh tier (Presque Isle to Charlevoix and Emmet counties)	43	46.8	3.[illegible]

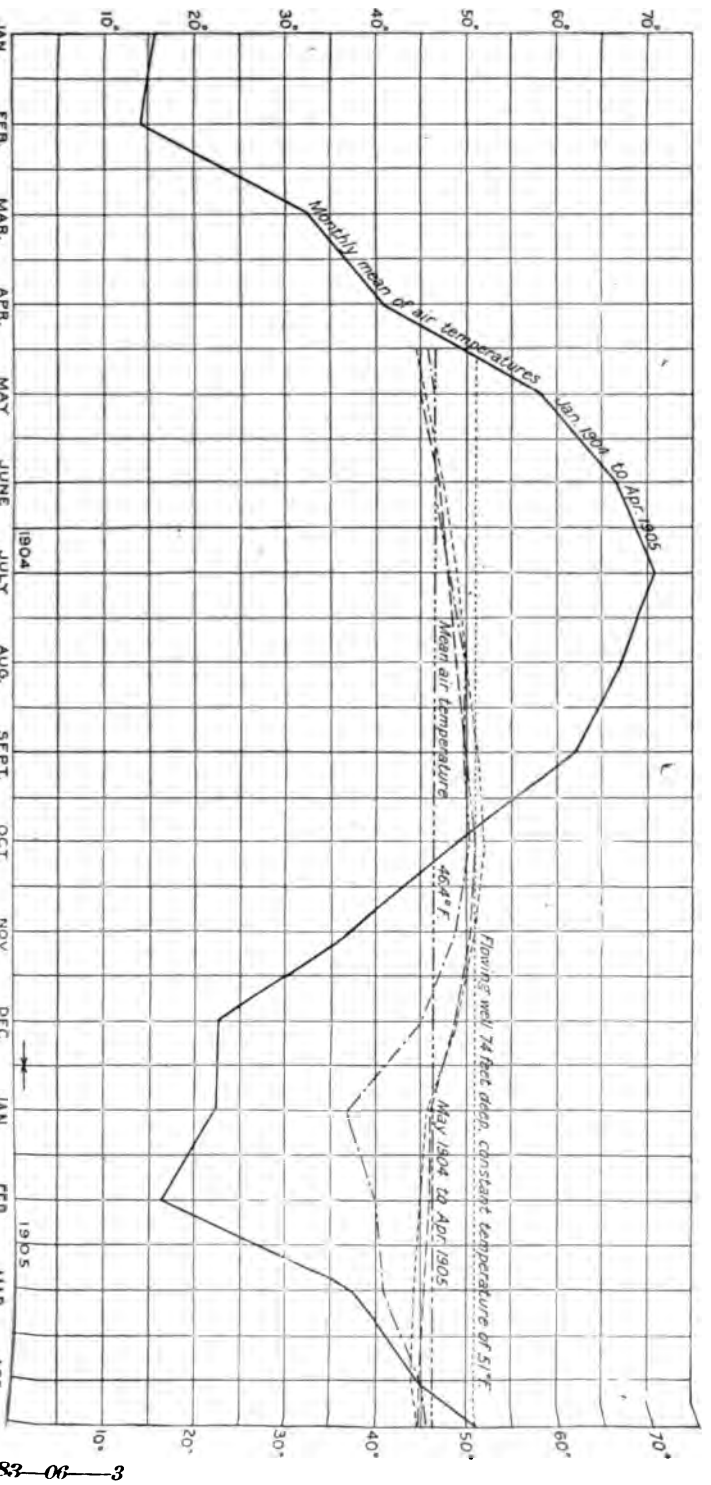
averages of water temperatures given in the above table are n the temperatures of strong wells which appear to have been to little surface heating. They fall slightly below an aver- sed on all the wells, weak and strong. The accompanying

2. General average of flowing-well temperatures in the Southern Peninsula of Michigan.

ig. 2) presents the results of a grouping of all the wells except hat are known to be subject to surface heating.

thly observations were made between May, 1904, and May, t Ann Arbor, Mich., on the temperature of springs and wells of *classes, an attempt being made* to include all the classes within

easy reach of the city. Three springs were selected—one on Sta street issuing from the base of a gravel deposit, another on the Whi estate west of the city issuing from the base of a till bluff, and a thi which bubbles up from the bed of a ravine on the Rash property the western part of the city. Five shallow dug wells and one de dug well were taken because of the various conditions which th include, one being in a ravine, another on the brow of a bluff, anoth on a gravel terrace, and two others on an elevated moraine, one bei covered and the other open. The deep dug well maintains a wat level 40 feet below the surface, while the shallow wells have wat within 5 to 22 feet of the surface. Two shallow tubular wells, in o of which the water stands near the surface and in the other at a dep of 18 feet, were selected, and two deep tubular wells which overflo The tubular wells showed very little range in temperature, but t dug wells varied greatly. The bubbling spring showed a steady ter perature, while the springs issuing from the hillside were influenc by the seasons. The lagging of the effect of summer heat and win cold was a matter of principal interest in connection with the obser tions on the dug wells, the effect of the former culminating in Oc ber and that of the latter about April. The accompanying diagr (fig. 3) sets forth this feature, while the observations are presented the following table:



Air temperature ——— *Shallow well with wooden pump* ------ *Shallow well with iron pump* — — — *Shallow well with windlass and bucket* —·—·—

FIG. 3.—Diagram showing fluctuations in air and well temperatures at Ann Arbor, Mich.

Observations on wells and springs in and near Ann Arbor, Mich., May, 1904, to April, 1905.

Name and location.	Class.	Pump.	Depth in feet.	Head in feet.	Temperature (°F.). May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Annual averages.
State street spring; base of gravel, piped several rods.	Issuing		0	0	51.2	53	54.5	55.5	54.8	53.5	50.3	47	45	42.5	42.5	46	49.8
White estate spring; base of bluff, piped several rods.	do		0	0	50.8	51	51.3	51.5	51	50.3	49.8	49	49	.....	49	49.7	50.2
Rash spring; bed of ravine	Boiling		0	0	51	51	51	51	51	50.8	50.7	51	51	51	51	51	50.95
Buehler well, in ravine	Dug	Wooden	12	−5 −10	45.5	47.5	49	50	51.2	52	51	49	45.8	45	44.3	44	47.86
Rash well, on bluff, 34 feet above Rash spring.	do	Iron	23	−22	45	47	48	48.9	49.9	51	50.5	48.8	46	46	45.5	45	47.6
Schaeberle well; on gravel terrace capped by clay.	do	Wooden	18	−9 −17	46.5	48.5	49.5	51.6	52.4	53	52	49	47.5	45.5	44	45.8	48.77
Levy well; on terrace sunk through gravel into till.	do	Iron	80	−40	48.3	49	49.8	50.5	51	51	50.5	50.5	50.3	46	48.3	48.3	49.5
Observatory well; on moraine, with plank cover.	do	None	15	−11 −14	45	46.5	48	51	52	52.5	50	46.9	41	37	43	41.6	46.2
Carroll well; on moraine near observatory, no cover.	do	Windlass	24	−20 −22	46.5	46.5	48	50	49.6	50.3	48.9	45	37	40	41	45	45.57
Niederhammer well; on slope of ravine	Tubular (2-inch)	Iron	36	−18	50	51	51	51.15	51.15	51.1	51.4	50.3	49.7	50	50.2	49.8	50.57
Dunn well; on South State street, in old Huron River channel.	Tubular	do	28	−2	49.8	50.5	50.3	51	51	51.5	50.8	50.5	50.5	50	50	49.5	50.45
Lutz flowing well in ravine	Tubular (2-inch)	None	112	+3	51.1	51	51	51	51	51	51	50.8	50.8	50.8	50.8	51	50.9
Hutzel flowing well; in ravine	do	do	72	[a] +5	51	51	51	51	51	51	51	51	51	51	51	51	51
Air temperatures at Ann Arbor, from daily observations at the observatory.					58.4	66.7	70.8	67.3	62.2	49.4	37.2	22.9	22.7	16.5	37.7	44.8	46.4

[a] Original head +22 feet; loss of head due in part to leakage around pipe.

LEGISLATION.

There are two important legislative acts in reference to Michigan ater supplies, copies of which are presented below:

[Act No. 43, Public Acts of 1897; 4484-4486, Compiled Laws, 1897.]

AN ACT to provide for the analysis of water in use by the public in certain cases.

The people of the State of Michigan enact:

SECTION 1. That in any case where any city, village, or township in this State shall be pplied with water for domestic uses by any individual, company or corporation, city or lage, or where there is within such city, village, or township any water in swales, wells, rs, or other places, which might be the cause of disease or epidemic, a sample of such er may be sent to the University of Michigan for analysis, by the mayor of such city or ge, or by any alderman or trustee of such village, or by the supervisor of any such town-, upon the resolution of the common council of such city, or board of trustees of such ge, or the township board of such township, for that purpose duly passed.

CTION 2. Upon receipt of such sample the regents of the University of Michigan shall a correct analysis of such sample of water to be made, and a correct statement of the rties contained therein, with a further statement whether or not such sample contains ubstance deleterious to health, and return such analysis together with the statement said to the person so sending the same, free of charge, except the actual cost of mate- and animals used in making such analysis and experiment.

TION 3. It shall be the duty of the board of regents of the University of Michigan to a record to be kept of every sample of water received under and by virtue of this e, and in no case shall a second analysis be required of the same water within one year t in the case of the breaking out of some disease among the consumers of such water, hen only upon the certificate of at least two physicians engaged in active practice in ommunity that in their opinion such disease arises from the use of said water.

proved March 26, 1897.

[Act 107, session of 1905.]

LL to regulate the use of artesian and other wells to prevent the waste of waters therefrom, and provide a remedy therefor.

people of the State of Michigan enact:

TION 1. Any artesian or flowing well, the water of which is unnecessarily allowed to waste in an unreasonable manner to the depletion or lowering of the head or reservoir of to the detriment or damage of other wells supplied from the same head or reservoir, be deemed a nuisance, and its owner and the owner of the land on which it is situated be subject to all the actions for abatement and damages in favor of the person or per- njured that are or may be provided by law for other nuisances or tortious acts.

TION 2. Where any well is supplied by a head, reservoir, stratum, or vein, or by per- ng waters common to other streams or wells, and the owner thereof or his lessee or re puts its waters to a use unreasonable or unnecessary, in view of the condition and ion of the land on which it is situated, and through such unreasonable or unnecessary wers or depletes the head, pressure, or supply of water of any spring or well dependent same head, vein, or stratum, to the detriment or injury of the owner or any person d to the use thereof, the well so unreasonably and unnecessarily used shall be deemed a nuisance, and its owner and the owner of the land on which it is situated shall be sub- all the actions for abatement and damages in favor of the person or persons injured re or may be provided by law for other nuisances or tortious acts.

TION 3. Where any decree is rendered under this act declaring any well a nuisance se of the waste or unreasonable use of its waters and directing the abatement thereof, decree *shall specify in some practicable* manner the daily amount or volume of water

that may be used or allowed to flow therefrom without violating such decree, and specify such reasonable time as to the court shall seem just within which the provisions thereof shall be carried into effect: *Provided*, That any such decree may be reopened at any time after entry on the question of reasonable use on a proper showing of change of circumstances or other equitable reason therefor.

FLOWING WELLS.

Although the number of flowing-well districts already exceeds 300, it is probable that many more can be developed in low places either among or along the borders of the moraines and in the valleys of streams. The fact that wells are usually placed near the dwellings and that the sites of the dwellings are naturally on well-drained and usually elevated points account for the small amount of testing that has been made on the lower land, where flows might be expected.

The flowing wells already in operation have been put to comparatively little use and there seems to be a general lack of appreciation of the applications that can be made of these fountains. It is a common thing to find flowing wells running to waste in dooryards in rural districts in seasons of drought when the gardens and lawns are suffering for lack of water. In many cases it would be necessary only to attach a hose to obtain means for properly irrigating the premises. The wasted water might also in some instances, by the installation of a hydraulic ram, be forced to tanks in the attics of farmhouses, where it would have pressure necessary for distribution through the buildings and would also afford a supply for fire protection. In some cases the wells have been used to fill ponds stocked with fish and thus yield a valuable resource for farm and market—a device which might be more generally adopted. The principal use to which flowing wells have been put, however, aside from furnishing water for domestic and farm use, is that of cooling milk in the dairy houses, the very uniform temperature of the water fitting it admirably for this purpose.

In some flowing-well districts a loss of head has been reported, and in many districts individual wells are either losing head or have fallen short of the full head customary at the time of their construction. Where the loss of head is general throughout a district it may be inferred that there is an overdevelopment by which the water is drawn out faster than it can be supplied from the surrounding formations. The Ann Arbor waterworks furnishes a case in point, the water drawn from the small field in which the wells occur having been sufficient to stop those on the border of the field from flowing. Often a single strong well on ground lower than the neighboring wells will draw down the head sufficiently to stop the wells from flowing. In cases of this kind the law pertaining to the restriction of artesian wells should be enforced. There seems to be a growing appreciation of the need for checking the flow of the strong wells and reducing the waste which is sure in time to work to the detriment of the district.

Flowing wells are often deficient in head and rate of flow because of ·fects in the casing which allow leakage into upper strata where the ater pressure is less than in the lower portion of the well. The head also deficient where water is allowed to rise around the casing. This in some cases due to imperfect driving of the casing and might be ıarded against. Any obstructions either in the bottom of the well · at the top tend to reduce the head. Instances are found where, ırough carelessness, wells which had been cut off near the surface of ıe ground were so filled by sand washed in from above as to cease ɔwing.

The district in southeastern Michigan in which a large number of ɔwing wells have failed was investigated and is reported upon by Mr. uller, who attributes the loss of head chiefly to drought and surface ·ainage.

Wells in certain regions have lost head through subsurface drainage, ·veral instances of which are found in the coal-mining region border- ıg Saginaw Bay. The extensive pumping necessary to remove ater and permit mining operations to be carried on draws down the ead for considerable distances around, and often deprives the border istrict of its flows.

The conditions under which flowing wells may be obtained are so arious that the reader is referred for detailed information to the pecial reports presented below.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES.

In the entire State there were at the beginning of the year 1906 ıbout 250 cities and villages and at least 15 State institutions pro- ·ided with waterworks systems. About 50 of the villages, however, ıse water chiefly for fire protection, and in some cases they have no listribution systems. The population of the towns and institutions ɔrovided with waterworks aggregated about 1,150,000 in 1900, ·hen the last Federal census was taken, but in most of the towns ı large part of the people have not connected with the public sup- ɔlies and still continue the use of private wells. On the basis of he number of taps reported it is estimated that in the cities with ı population between 10,000 and 100,000 about two-thirds of the ɔeople are connected with the public supply, and in towns of less han 10,000 population one-half or less are thus connected, while in)etroit, the only city with more than 100,000 population, nearly all ıre connected. From this it appears that the probable actual users ɔf public supplies are between 750,000 and 800,000, say 775,000, or 32 per cent of the entire population of the State in 1900 (2,420,982). Of these, nearly 600,000, or about 24 per cent of the population, are supplied from surface water and less than 200,000 from wells. Of those not *connected with public* supplies probably not more than

20,000 depend upon springs and surface waters, while about 1,625,000, or two-thirds of the State's inhabitants, depend upon private wells.

There are 37 towns on the borders of the State, with a population of about 510,000, which obtain public supplies from the Great Lakes and their connecting streams—St. Marys, St. Clair, and Detroit rivers. The metropolis, Detroit, with a population of about 300,000, is among the number. The water from this source is not so hard as from the majority of the wells, and is therefore especially suitable for boiler use. In an unfiltered state it is often found to be unwholesome and in some cases dangerous for drinking, because of contamination in the vicinity of intake pipes. The worst epidemics of typhoid in the State have prevailed in towns taking their supply from this source. It is therefore incumbent on the cities and villages thus situated to put in filtration plants with up-to-date methods of purification. Indeed, all surface water, including that from springs, streams, and inland lakes, should be properly filtered before it is used for drinking or other domestic purposes.

Many of the inland towns have taken public supplies from the streams and inland lakes, the population of such towns aggregating about 300,000. In not a few cases, however, the domestic use of the public supply is largely restricted to closets, baths, and lawn sprinkling, while private wells are used for drinking, there being considerable prejudice against drinking the public supply, not alone for fear of its contamination, but because it is less palatable than the well water. This is especially true in hot weather, when the surface water becomes too warm to readily quench thirst. The streams and lakes are seldom rendered objectionable for drinking because of a muddy condition due to freshets, for on account of the prevalent porosity of the soil the rainfall is absorbed, and except in clayey districts is largely supplied to streams by underground seepage. Only the most violent rains cause much disturbance of the streams. Michigan is more highly favored in this respect than the neighboring States.

Of the cities drawing public supplies from wells only 5 had in 1900 a population of more than 10,000, namely, Jackson, Kalamazoo, Lansing, Ann Arbor, and Manistee. The supply at Jackson is from deep wells in sandstone and probably is not excelled by any city in the State. Lansing also obtains its supply from sandstone. The three others obtain supplies from glacial deposits or from the overlying gravel. Many smaller cities, the majority of villages with public supplies, and several of the State institutions are entirely supplied from wells, there being 29 using wells in rock and 104 using wells in the drift, while 15 others are supplied in part from wells and in part from surface water. The rock wells are chiefly from

sandstone, those from limestone being almost wholly restricted to the Northern Peninsula and to the northern part of the Southern Peninsula. Many data concerning the public as well as private supplies from wells will be found in the special reports herewith presented.

WATER SUPPLIES OF MUSKEGON COUNTY.

By C. D. McLouth.

TOPOGRAPHY.[a]

Muskegon County borders Lake Michigan near the middle of the east side of the lake, the city of Muskegon being the county seat. It is drained centrally by Muskegon River, while White River crosses its northwest corner and Crooked Creek, a tributary of Grand River, its southeast corner. Along the shore of Lake Michigan are several wide-mouthed streams, some of which head but a few miles inland. Muskegon and White rivers also enter lakes near their mouths. The county is very largely a sand plain, though there are prominent moraines in the eastern end and weaker ones in the northwestern part, in which productive land is found. On the sand plains water is ordinarily obtained at depths of 25 to 50 feet, the water table being in harmony with neighboring streams, but on the moraines the wells vary greatly in depth within short distances, irrespective of elevation, because of the irregular distribution of water beds.

WATER-DISTRIBUTING SYSTEMS.

In Muskegon County four communities have public distributing systems, viz, Muskegon, North Muskegon, Whitehall, and Montague, while Casnovia has fire cisterns. In all of these the water is used for fire protection and for lawns and gardens, and in all except Montague and Casnovia for general domestic use as well. In Muskegon a considerable quantity of the water is used for general mill purposes. In Whitehall such use is limited to refilling boilers.

In the Muskegon system water flows from the lake by gravity into two wells at the pumping station, from which it is distributed by direct pressure through 4 miles of 24-inch, 2 miles of 16-inch, 3 miles of 12-inch, 1 mile of 10-inch, 1 mile of 8-inch, 26 miles of 6-inch, and 11 miles of 4-inch mains.

At Whitehall the ordinary supply is pumped from four wells described on pages 28–29. The water is stored in large tanks, from which it is drawn and forced through the mains by a pump larger than those working in the wells. Before the wells were opened the supply was drawn from White Lake, and the old intake is still con-

[a] By Frank Leverett.

nected with the distributing pump and is used in case of fire or other emergencies.

At Montague water from a small brook is collected above a dam and pumped into the mains.

Casnovia has a municipal supply stored in cisterns for use in fire protection.

The following table gives the statistics for the waterworks systems in the towns. All are owned by the municipality and all use steam power for pumping.

Statistics of water-distributing systems, Muskegon County.

Town.	Population (1900).	Source of water.	Depth of well.	Water bed.	Quality of water.	Pump.
			Feet.			
Muskegon	20,818	Lake Michigan, at 41 feet.	20	Sand	Medium hard	Holly vertical.
North Muskegon	513	Bear Lake, at 7 feet.	None.	do	Soft	Walker.
Whitehall	1,481	Four wells	67	do	Medium soft	Downie deep well double-acting.
Montague	998	Brook reservoir		Mucky	Soft	

Town.	Pressure.	Daily capacity.	Mains.	Hydrants.	Taps.	Cost.	When built.
	Pounds.	*Gallons.*	*Miles.*				
Muskegon	a40, b85	6,000,000	48	600	21,000	$450,000	1891
North Muskegon	c40, b160	1,000,000	5	40	175	28,000	1891
Whitehall	c40, b120	72,000	4	40	160	20,000	1892
Montague	b170		1.5	17		4,350	

a Domestic. b Fire. c Ordinary.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Muskegon County.

Town.	Source.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bailey	Open and driven wells	10	30	25	30	—15	Small.
Canada Corners	Wells and springs	9	20	20	20		Large.
Casnovia	Open and driven wells; cisterns for fire.	25	100			—40	Small.
Holton	Driven wells	25	30	25	25		Large.
Lake Harbor	Driven wells and lakes	25	35	30	30	—20	Small.
Ravenna	Bored wells	10	130	30	130		Do.
Slocum	Driven wells	12	20				Medium.
Sullivan	do	24	32	24		—20	None.

FLOWING WELLS.

GENERAL STATEMENT.

The flowing wells known in this county seem to indicate seven districts, which may be designated (1) White Lake, (2) Muskegon Lake, (3) Lake Harbor, (4) Spring Lake, (5) Moorland, (6) Fruitland, and (7) Casnovia.

The first four of the districts named are very much alike in surface ıtures. Each includes a lake, from which it is named, and the narw shore margins and the underlying portions of the more or less tensive marshes and river valleys continuous therewith. The elonted lake troughs all have a general direction from northeast to uthwest and extend from about 4 to 7 miles inland from Lake ichigan, into which all have outlets. The principal feeders of these kes enter through marshes and the valleys in which they flow hibit such features of continuity with those of the lakes as to leave tle doubt that the lakes are but drowned valleys where the streams ıce flowed directly into Lake Michigan, when its level was lower relavely to the land surface. The land in the region including these stricts is mostly a plain of glacial sand, having an elevation of about) feet[a] at the north and descending gradually to lake level at the uth. A moraine traverses all these districts, except perhaps that Spring Lake at the extreme south, its prominence compared with e sand plain being much greater northward. Throughout this gion the surface stratum of coarse sand generally extends to some pth below the lake surface, consequently the water that falls upon e land in the vicinity of the lakes and their larger tributary streams ters down near to surface level of the lakes, thus making the water ble low.

The other three districts differ from the lake districts so greatly and ve so little in common among themselves that no general description applicable.

WHITE LAKE DISTRICT.

Topography.—In the vicinity of White Lake the crest of the moraine ›f medium height and has a general direction nearly at right angles the length of the lake. It is intercepted by the marsh, White ver seeming to have cut a gap about 1½ miles long in the moraine. ntague lies north from the head of the lake and Whitehall on the t about a mile down the lake. The crest of the moraine lies oute both corporation limits, running northward on the east side of ıitehall and nearly northwest on the north side of Montague. The rainic till, at an elevation of about 50 feet, extends into the north- part of Montague and to the lake bluff in the northern part of ıitehall, constituting perhaps one-half the area of the latter place. ›m White Lake to Lake Michigan the surface is mostly a sand in, which is 50 or more feet above lake level where it meets White ce, in the vicinity of Montague, and seems to overlap the edge of moraine. The same sandy features continue to the south and of the lake, but with less even surface.

[a] All altitudes, unless otherwise stated, are given in feet above Lake Michigan.

Wells.—All the wells, except one at the United States life-saving station at Lake Michigan, are in Montague and Whitehall. Thus a large part of the district is undeveloped. Most of these wells are situated near the border of White Lake, the farthest being not more than 1,000 feet from the water margin, and a number are on docks built into the lake. More than one-half of the wells are less than 5 feet above Lake Michigan. The shallower ones, which are also the most remote from the lake shore, are on higher ground, between 10 and 15 feet above lake level.

The wells which have flowed in this district number somewhat more than 25. Most of them are still active and yield about 70,000 gallons daily, including 50,000 gallons pumped from four wells at the Whitehall municipal plant.

The depth of the wells varies greatly. The shallower ones referred to above are near the edge of the moraine in Montague and vary from 28 to 40 feet in depth, one of them being possibly only 18 feet. There are eight wells clearly belonging to this group.

The most satisfactory record obtained was that for the well in the village hall, driven by R. D. Hall, the village marshal, in the autumn of 1903. The record follows:

Record of well at Montague.

	Depth (feet).
Muck	4-5
Red clay	5-6
Quicksand	7-8
Blue clay	15
Fine sand, coarse sand, and water.	

Another well which should probably be classed with those just described is in the Montague iron works, about 400 feet toward the lake from the village hall well. Its record is very indefinite, although it was driven in the spring of 1904 and is the latest well opened in that vicinity. The depth is stated to be between 40 and 50 feet. It is remarkable in having water which stands several feet lower than in the others. The water from all these wells is soft.

Nearer the lake and on lower ground are two old wells said to be between 60 and 70 feet in depth, both of which are more "sulphury" and "irony." No definite records were obtained. The temperatures were 0.5° and 1.5° C. higher than that of the water from the well in the village hall, the difference of 1° between the two evidently being caused partly by unequal exposure.

On the Whitehall side the four 6-inch wells from which the village supply is pumped are 67 feet deep, the strata being as follows:

Record of Whitehall village wells.

	Depth (feet).
Sand	1[illegible]
Blue clay	5[illegible]
Sand	6[illegible]

About one-half of the wells in Whitehall are stated to have depths running between 55 and 70 feet, and presumably their records are represented in a general way by that of the village wells. The well of the Nufer Cedar Company, located some 700 feet southwest from the pumping station, may be taken as an example. Its elevation is several feet lower and its depth 57 feet, all through blue clay below a level 10 feet lower than that of the water of White Lake.

The deepest well found is the one at the life-saving station. This has a well-authenticated depth of 153 feet, entirely through blue clay below 12 feet. The nature of the water bed is not known. The well was driven by W. H. Dennis in 1887.

At the office of L. T. Covell, very near the head of the lake, is a well 129 feet deep, which, so far as known, is next in depth to the Government well. Its water is decidedly strong in mineral quality. The character of the strata is not remembered by the owner, but he states that there were sand, clay, and some marl, and that turbid flowing water was found at 54 feet. The well was driven by Peter Denneau, of Montague.

It appears, therefore, that there may be several sources of the flowing wells in this district. The two deepest ones must penetrate nearly to bed rock, if, indeed, they do not reach it. It seems fair to suppose that the shallow wells in Montague have their sources in the moraine and that the veins tapped are not essentially different from those that break out in numerous springs along the foot of the bluff. The municipal wells of Whitehall represent another class supplied from a sand stratum between strata of blue clay which probably lie below the greatest depth of White Lake.

Mr. W. F. Nufer, of Whitehall, asserts positively that the first well to flow in this district is the one farthest to the south in Whitehall and located on the property of the New York Mill Company. It was put down about 1868 by Mr. George M. Smith of the firm of C. A. Alley & Co. Its depth is 107 feet. It is still flowing.

Mr. J. W. Young, of Montague, claims that the well in the blacksmith shop at the corner of Water and Spring streets antedates all others in Montague and Whitehall. The well was dug with a spade, evidently without expectation of finding a flow. After the hole overflowed with water a pipe was inserted and the earth was returned. Mr. Young places the date at 1873.

The well of Mary Reed (see p. 31) is stated to have been put in about 1870.

Quality and uses of water.—The character of the water has been referred to above in relation to the various depths. Mr. S. J. Lewis, of the United States Geological Survey, analyzed samples from well No. 25 in the Montague village hall, 37 feet deep, and from No. 18 on village property near Church street, said to be 62 feet deep, and found

the chlorine content to be very low compared with that in water from Muskegon wells. (See p. 37.)

Most of these wells were opened to get water for drinking purposes. Three of the shallow Montague wells along Water street are in private houses, and the water serves for general household uses. The one in the Montague iron works supplies water for cooling. The water from the well at the life-saving station is reported to be "soft" and suitable for "family use." The Whitehall village supply is taken in houses, stores, and stables, and used on lawns and gardens, for fire protection, and in the mills for refilling boilers.

Head.—Except in a very few cases the water head is not known. Mr. Berndt Carlson, keeper of the life-saving station, found by careful trial that the water there would rise 8.5 feet above Lake Michigan. Water from the well in Montague village hall has been carried in a pipe that was found to be about 12 feet above the Pere Marquette rail at the station, which indicates a head of 20 feet or more above lake level, and from appearances a similar head is present in the shallow wells, except in that at the Montague iron works, which does not flow, although, according to the statement of Mr. R. D. Hall, who was present when the well was finished, the water then rose about 2 feet above ground.

The Whitehall municipal wells now rise only a foot or two above the ground, or about 6 or 7 feet above the lake. Mr. J. H. Williams, who was president of the village at the time the wells were opened in 1892, states that the rise then was fully 6 feet above the ground.

It is notable that the wells which are pumped, viz, those at the Whitehall plant and the Montague iron works, have suffered a loss of head. At the iron works the maximum amount pumped per minute is estimated at 10 gallons, and this is sometimes continued for hours. The supply has not been noticed to fail. At Whitehall waterworks the four wells are placed so that the lines joining them form a trapezium, the least distance between two wells being about 25 feet, the greatest about 50 feet. When one of these wells is pumped alone at full capacity the water is lowered slightly in the others. When all the wells are in good order and are pumped simultaneously the yield per well is estimated at about 80 per cent of that when pumped singly.

The opening of these wells caused a striking instance of loss of head in a well located about 200 feet northward and owned at that time by Mr. A. T. Linderman. This well was 82 feet deep and would flow at a height a little above ground, but ceased when the village wells began to flow. The depleted well appears to be on slightly higher ground. It is stated that by digging down and lowering the pipe the water was found to have fallen about 4 feet, and that the flow was kept up at the lower level for a time. The well is now not in use.

About 120 feet still farther north is a flowing well formerly owned y Charles Johnson, but now the property of E. Duttenhoefer. The ow of this well was diminished at the same time as that of the Linderan well, but not to so great a degree. It does not flow at present.

Many of the wells continue to yield water nearly or quite as bundantly as when they were put in. A well by the mill of L. T. ovell, which was flowing about 5 gallons a minute in the summer of 900, was not flowing in November, 1904. The cause is not known. he flow of the well at the life-saving station is stated to have diminhed. A well at the corner of Colby and Lake streets in Whitehall, wned by Mary Reed, was put in about the year 1870 and had ceased o flow about ten years ago from accumulation of sand and silt. Vhen it was pumped out, the flow was restored, and it now yields bout one-half gallon a minute. The pipe is 4½ inches in diameter and he depth 96 feet. This is possibly the oldest flowing well in the district, although the claim it disputed.

In November, 1904, three of the Whitehall public wells were useless, nd the entire ordinary supply was being drawn from one well. In 'ebruary following one of the three was being pumped with a modrate yield. The cause of stoppage was not definitely known. Mr. 'harles Deane, the engineer, thought that "magnesia" had accumuated on the sieves and that this, with the fine sand in which the sieves ie, effectively clogged the meshes when the pressure of the pump was pplied. Mr. Deane asserts that the sieves do not corrode.

Cost of wells.—A few typical wells cost as follows:

Cost of wells in White Lake district.

Owner.	Depth.	Diameter.	Cost.	
			Total.	Per foot.
	Feet.	*Inches.*		
United States Life-Saving Service	153	2	$174	$1.20
Montague village	37	2	25	.67
Nufer Cedar Co	57	2.5	57	1.00
Whitehall village	110	2	100	.91

MUSKEGON LAKE DISTRICT.

Topography.—The moraine occurs here nearly parallel to the shore of Lake Michigan and about 3 miles inland. It is decidedly lower than it is to the north, barely exceeding 55 feet at its greatest elevation, and being entirely covered by sand except at a prominence on the south shore of Muskegon Lake, known locally as "Brewery Hill." About 1 mile of the moraine has been cut out in forming the trough occupied by Muskegon Lake, and the section of the bluff where the moraine meets the lake on the north side shows 20 feet of sand overlying the ridge.

This district properly includes Bear Lake, a tributary of Muskeg Lake from the north. The water head, as shown below, seems decrease toward the upper end of Muskegon Lake, and the san decrease continued would extinguish it 2 or 3 miles upstream from tl head of the lake, thus making the limit of the district some 10 mil inland from Lake Michigan. These indications, however, are nc borne out by a well belonging to Leon J. Smith in the marsh in th NE. ¼ sec. 17, T. 10 N., R. 16 W. The well is about 2 miles northeas from the upper well in the lake proper and flowed with a head of 1 feet when first opened in 1898. The surface is probably not less thar 6 feet above the lake, thus making the head above the lake about 1 feet. It would seem, therefore, that the river valley may be expectec to afford flowing wells for many miles up.

Wells.—With very few exceptions, the wells in this district are on the water side of the original shore line. They were located on docks anc built land adjacent to the sawmills to furnish drinking water for the mill crews, and their elevations therefore are generally very low The highest well, which belongs to Frank Alberts, is on the north shore of Muskegon Lake, on natural land 9.5 feet above the lake.

About 15 flowing wells have been opened here. The total natura flow of water from those remaining active is about 15,000 gallon daily, to which must be added 50,000 to 100,000 gallons pumped fron the well at the plant of the Central Paper Company. About 10 well are now flowing.

In this district most of the wells are so old that reliable informatior as to their strata is not obtainable. Three comparatively new wells two on the north side and one on the south side of the lake, have record that are presumed to be accurate. Of these three, the one on the south shore, owned by the Central Paper Company, located in the SW. ¼ NW. ¼ sec. 35, T. 10 N., R. 17 W., has a record as follows:

Record of well of Central Paper Company, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	40	4
Blue clay (lake clay?)	197	23
Hardpan	2	23
Sandstone	57	29

Depth to water, 237 feet. Surface elevation, 13 feet above Lake Michigan.

Across the lake, 2 miles slightly east of north from the site of the paper mill, in the SE. ¼ sec. 23, T. 10 N., R. 17 W., is a well on land owned by Dr. J. G. Jackson, which was drilled by C. C. Jacks in December, 1901. The record stated for this well is as follows:

Record of Jackson well near North Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
›bably morainic till)	50	50
ıd	3	53
	7	60
ıd	2	62
›bably marly lake clay)	170	232
ın"	2	234
aterial"	2	235
ın"	1	237

: elevation, 1.5 feet above Lake Michigan.

: third recent well is 4 miles nearly due northeast from the paper n the SE. ¼ NW. ¼ sec. 18, T. 10 N., R. 16 W. It was drilled ›w & Campbell by C. C. Jacks in 1901. The record was given as 's:

Record of Gow & Campbell well, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
	40	40
	164.5	204.5
rock"	1	205.5
	1.5	207

e elevation, Lake Michigan level.

: surface stratum of clay in the Jackson well is doubtless the edge moraine of till, the crest of which lies about one-half mile east a cover of sand, as stated above. The well is by the edge of the at the outlet of Bear Lake, where the sand cover has been worn The other two wells are probably beyond the extent of the ne, one west, the other east.

ırly due south, 1½ miles from the Gow & Campbell well and about 's east-northeast of the paper mill well, is a deep hole, drilled ıl years ago in search for oil. The record was carefully taken and ollows:

Record of well about 3 miles east-northeast of paper mill, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
	65	65
y (?)	160	225
hardpan"	10	235

: elevation, about 10 feet above Lake Michigan.

: four records given exhibit a uniformity that is significant. The ilateral drawn with the wells at the angles includes about one- f Muskegon Lake and more than 50 per cent of the deep wells borders. It is probable that the records of all the wells are ially like those given. The bed rock penetrated in the two

borings on the south side is a white micaceous sandstone of the Marshall group. None of the flowing wells are known to extend into this rock, but it is presumed that all, with one exception, reach it and that it forms their water bed. The water pumped from the well at the paper mill is evidently from the same source and would flow if the elevation of the well were a few feet less.

The exceptional well to which reference has just been made is in the shade-roller factory of the Stewart Hartshorn Company, near the foot of "Brewery Hill," mentioned above as a conspicuous part of the moraine. The well is 57 feet deep, and the strata penetrated were given as follows by Hubert Young, the driller:

Record of well of Stewart Hartshorn Company, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sawdust	7	7
Lake sand	10	17
Marly clay	10	27
Sand and clay	3	30
Sand and gravel	10	40
Open water-bearing sand	3	43
Quicksand	7	50
Sand and clay	7	57

At 40 feet water was found that rose about 6 feet above Lake Michigan. At 57 feet the head was about 10 feet.

Assuming the depths of wells approximately correct as given, the inference follows that there is a general and decided dip of bed rock to the west, but by comparison of the two most reliable records only (those of the experimental oil well and the paper-mill well) the dip appears much less.

Head. The head evidently varies somewhat in the wells of this district, appearing to rise westward and northward. The highest rise of water was observed at the Alberts well, located near the mouth of Greene Creek in the NW. ¼ NW. ¼ sec. 22, T. 10 N., R. 17 W., where there is a strong flow of water at about 12 feet above Lake Michigan. The owner states that about twenty years ago the water from this well was piped into the second story of a boarding house near by, rising 18 feet above the surface or about 16 feet above the present exit, making about 28 feet above Lake Michigan. The statement of Mr. Alberts can be questioned only on the supposition that the house stood on somewhat lower ground, so that he was deceived as to the actual height. A man living near the well states that the present head is about 15 feet above Lake Michigan.

At the paper-mill well, nearly 2½ miles to the south, the rise of water is between 10 and 12 feet above the lake. At the Jackson well, somewhat less than a mile south of east, the head is about 9 feet. Four miles north of east from the Alberts well, one of the Gow & Campbell wells, on the site of a mill formerly operated by John Tor-

had a head of 7 feet at the time of Mr. Torrent's ownership. At
ell of the Racine Boat Company, about 3 miles up the lake from
paper mill, the head is 7½ feet. This well is 3 miles from the
ts well also, and thus indicates a loss of head of about 1 foot a
northeastward and of somewhat more than twice that amount
eastward.

ry few instances can be found in this district in which a well is
n with certainty to have lessened the flow or lowered the head
ers. As indicated before, the Alberts well (No. 6) has undoubt-
decreased in both flow and head. The owner believes that the
leaks underground, but whether the change is due wholly to this
the tapping of the water bed in a number of other places is
rtain.

out 200 feet from the paper-mill well and on the same premises is
er well of like diameter (8 inches), which was made about the
time, but was drilled to a depth beyond 1,600 feet in search of
Only a trace of oil was found, and the inner tube was withdrawn,
ng the casing, so that the water was admitted at the bed-rock
. It was intended to use water from both wells, but trial proved
when one well was pumped at the maximum rate of 150 gallons
ute the water was lowered decidedly in both to about the same
It seemed that nothing was to be gained by operating both
, and the deeper one was abandoned. Evidence of free commu-
ion between the wells now appears constantly in the presence of
ith the water pumped from the shallower well.

en the well by the mill of Gow & Campbell, at North Muskegon,
pened in 1901, no effect was noticed in the flow of the other three
in the immediate vicinity. But when the new well was tested,
tting on a boiler injector, which drew about 150 gallons a min-
he flow of one of the wells, 700 feet distant, ceased while the
tor continued in action. The combined natural flow of the two
is about 1 gallon a minute.

cording to the evidence collected, the yield of wells in this district
ot materially changed in the aggregate, and in very few instances
individual wells ceased or greatly diminished their flow except
causes having no relation to the source or supply. Well No. 2,
n commonly as the Blodgett well, has become isolated from the
by the wearing away of the dock on which it was built, and is
to have ceased flowing because of obstructions thrust into the
r part of the pipe by meddlesome persons. A case has been
ioned in which it was believed that leakage in the pipe had dimin-
the apparent yield. Incrustation doubtless chokes the pipes of
ells more or less. Engineer Metcalf of Gow & Campbell's mill
d that 700 feet of pipe conducting water from well No. 8 was half
with "magnesia" during one summer.

A well on the Magoon & Kimball dock is stated by Mr. Jacks to be choked with "muck," by which he means a material like quicksand or silt that has filled the lower part of the pipe.

In the severe winter of 1903–4, two of the four wells on the premises of Gow & Campbell (Nos. 8 and 9) stopped flowing for about two months. Observers of the phenomenon think the cessation was not caused by freezing in the pipes.

A well near the intersection of Western avenue and Eighth street was probably the first to flow in the district. It was put down beyond 2,000 feet about the year 1868 by parties prospecting for salt. Mr. Hubert Young states that two pipes were afterwards planted so that water was delivered by one from a depth exceeding 300 feet and by the other from a shallower source, the deeper water being much the stronger in mineral qualities. This well flowed until a few years ago, and furnished an abundant public supply greatly relished by horses. The site is now owned by the Pere Marquette Railroad Company and is covered by a shed used in storage of coal. The well is supposed to have been stopped by plugging the pipe.

Quality and uses of water.—With a single known exception these numerous wells were opened to obtain suitable water for drinking. The flavor of the water, which is variously called "irony" and "sulphury" as well as salty, is not pleasant to many at first, but becomes agreeable after continued use. The healthfulness has always been found superior in comparison with water obtainable from any other source except Lake Michigan. Before a satisfactory public supply was obtained for the town, people living near carried water from these wells to their houses. The water from Doctor Jackson's well is now used in culinary processes.

The water from the well of the Central Paper Company is used for general mill purposes, especially for cooling. The temperature given is 11° C. or 51.8° F.

The only complete analysis found is that of the well belonging to the Central Paper Company, which follows:

Analysis of water from well of Central Paper Company, Muskegon.

	Parts per million.		Parts per million.
Silica	12	Total evaporating residue	2202
Alumina	22	Total hardness	181
Iron oxide	Trace.	Temporary hardness	87
Sulphate of lime	227	Permanent hardness	94
Carbonate of lime	156	Nitrites and nitrates	0
Calcium chloride	87	Phosphoric acid	Present
Magnesium chloride	254	Free ammonia	0
Sodium chloride	1307	Combined ammonia	1.7
		Albuminoid ammonia	.42
	2065	Sediment	36

Color, none. Appearance, turbid. Odor, none. Taste, salty. Reaction, neutral.

On the following table are given, in addition, the results of a number of partial analyses of water in the vicinity of Muskegon. The high chlorine constituent is considered as due to leakage from deep saline rock wells in the vicinity. The Montague samples were from wells in the village street sunk to obtain water for fire protection and other purposes. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of water near Muskegon and Montague.

[Parts per million.]

	1	2	3	4
Color	Not det.	10	5	5
Iron (Fe)	Minute trace.	Slight trace.	Trace.	Strong trace.
Chlorine (Cl)	59	64	1.5	1.5
Carbon dioxide (CO_2)	63.32	62.88	77.39	84.86
Sulphate trioxide (SO_3)	83	99	10	10
Hardness (as $CaCO_3$)	Not det.	139+	139+	139+

S. J. Lewis, analyst. 1. J. G. Jackson; depth, 237 feet. 2. Hackley & Hume; depth, 230 feet. 3. Montague village; depth, 60+ feet. 4. Montague village; depth, 37 feet.

The water from the shallow well belonging to the Stewart Hartshorn Company was analyzed for sanitary purposes by Davenport Fisher, of Milwaukee. The analysis follows:

Analysis of water from well of Stewart Hartshorn Company, Muskegon.

[Parts per million.]

Total solids	440	"Free ammonia"	.03
Chlorine	33	"Albuminoid ammonia"	.068
Sulphate of calcium	.184	Nitrogen as nitrates	110

The following comments are culled from a letter by Mr. Fisher, which accompanied the report:

The water is contaminated with sewage or vault seepings. * * * The salt, represented by chlorine, also comes from the same source. * * * Though such water may be safe for a long time, it might at any time bring disease germs and any health officer would condemn it.

LAKE HARBOR DISTRICT.

Topography.—In the lower portion of the district the sand plain has an elevation of about 15 feet, increasing gradually away from Lake Michigan and reaching about 40 feet above the bed of Black Creek or 50 feet above the lake at the location of the upper well near Cloverville. The moraine lies about 2 miles inland. It is very low, appearing only as a clay bed a few feet under the level sand surface.

Wells.—Only one flowing well is known in this district. It is in the valley of Black Creek on land owned by Doctor Gordon, of Muskegon, in the NE. ¼ NE. ¼ sec. 2, T. 9 N., R. 16 W. This well is about 6 miles from the Lake Michigan shore line and about 5 miles from the only other deep well known in the district.

No accurate record of the well could be found, but it was put down to a depth of 1,500 feet or more in the season of 1903 by parties prospecting for oil. The elevation is estimated to be about 6 feet above the bed of Black Creek under the Grand Rapids and Indiana Railroad, somewhat less than half a mile distant, indicating an elevation of between 15 and 18 feet above Lake Michigan. Bed rock is stated to be more than 300 feet below the surface, and the water is thought to come from a crevice in the rock at a depth of 340 feet. The temperature is 11° C., or 51.8° F., which would indicate a depth of not more than 250 feet.

The 8-inch casing put down to bed rock by the drillers was not removed and stands about 3 feet above ground. The inner pipe was removed and the casing plugged at the top with a block of wood, leaving a hole about 1 inch in diameter. From this opening water gushes up about 10 inches, flowing 16 gallons a minute, or nearly 25,000 gallons daily. A resident of the neighborhood asserts that he saw the water rise at least 10 feet above the surface when the pipe was being driven. This shows a head of no less than 25 feet above lake.

The quality of the water, judged by taste, is essentially like that of the deepest Muskegon wells but probably less salty.

The only other deep well found in the district is the property of the Forest Park Association and is located in the SE. ¼ SE. ¼ sec. 12 T. 9 N., R. 17 W. The surface is between 25 and 30 feet above the lake and the water rises to about 12 feet below the surface, or to 13 to 18 feet above the lake. The record given by C. C. Billinghurst is Sand 15 to 18 feet, clay to 6 inches from bed rock; total depth 218 feet. The water bed is called "shaly," but is undoubtedly the same sandstone found in the Muskegon wells. The water is used for drinking and by some for cooking, but others find it undesirable for the latter purpose on account of its "mineral" qualities. When raised with an ordinary hand pump, the water has always been turbid. An attempt to siphon it over the lake bluff has not been entirely satisfactory, but the turbidity was corrected while the siphon flowed. A summer population of about 30 people is supplied from the well which is said to have cost $250.

Although the elevation of the land has prevented this well from flowing, it is believed that the water is from the same source as that of the deep Muskegon wells and the Cloverville well. Comparing its head with that of the latter well about 5 miles distant, it is seen that there is an average gain in head of at least 1 foot a mile up the valley of Black Creek.

SPRING LAKE DISTRICT.

Topography.—Only a small portion of the upper part of Spring Lake is in Muskegon County. The land is generally sandy, with clay lying near the surface in many places. The general surface elevation is between 25 and 30 feet. In the near vicinity of Fruitport village, where the wells are located, water saturates much of the soil to the surface where not removed by artificial drainage.

Wells.—The only flowing well found in the portion of the district lying in Muskegon County is in the SW. ¼ sec. 35, T. 9 N., R. 16 W. This well is on the property of the Spring Lake Iron Company and has flowed since 1883, when it was bored to furnish water for the employees of the company working at the furnace. The present measurable flow is about 5 gallons a minute, which is less than formerly, but some of the water is known to escape through a leak in the pipe below ground. The surface elevation is 16 feet, and the head about 26 feet.

A partial record of the well was given by an employee who aided in the boring, as follows:

Record of well of Spring Lake Iron Company, Fruitport.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	10	10
Quicksand	22	32
Blue clay	60	92
Light sandstone	½	92½
Gravelly clay	8	100½
Solid gravel	4	104½
Yellowish mucky clay	3	107½
Blue shale	2	109½
Sand and clay in thin alternate layers	12	121½
Blue sandstone	½	121⅞
Grayish limestone	2	123⅞

The total depth of the well was stated to be 150 feet, and that depth was verified by Mr. J. C. Ford, president of the company. The temperature, 12° C., or 53.6° F., suggests a greater depth. A partial analysis of the water follows:

Analysis of water from well of Spring Lake Iron Company, Fruitport.[a]

	Parts per million.
Sodium chloride	3,467.17
Magnesium chloride	327.15
Calcium chloride	937.14
Potassium sulphate	91.43
Calcium sulphate	76.72
Calcium bicarbonate	1,119.15

The only other deep well in this portion of the district is on the resort property now owned by the Grand Rapids, Grand Haven and

[a] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

Muskegon Railroad, and located in the NW. ¼ SW. ¼ sec. 36, T. 9 N., R. 16 W. This well does not flow, the elevation being over 25 feet above Lake Michigan. It was opened about 1871. The record on file in the office of the Spring Lake Iron Company follows:

Record of well of Grand Rapids, Grand Haven and Muskegon Railroad, sec. 36, T. 9 N., R. 16 W.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	30	30
Blue clay	140	170
Hardpan and gravel	9	179
Blue sand rock	24	203
Blue shale	5	208
Marshall sand rock	41	249
Blue shale	6	255

Some claims of medicinal properties have been made for the water. Before the well became the property of the railroad it was on public ground and the water was freely used by citizens of Fruitport. Formerly the water was shipped in carloads to places as distant as New Orleans and used for curative purposes in cold and hot baths.

MOORLAND DISTRICT.

Topography.—This district, indicated by a single well, is presumed to be coextensive with the great marshy region that covers about one-half of Moorland Township and extends into the eastern part of Eggleston. The main branch of Black Creek, which flows into Lake Harbor, has its origin in the marsh. At Moorland station, where the well is located, the surface elevation is about 95 feet. On the south the marsh area terminates in gradually rising land that merges into rolling surface of till. On the east it is separated from the valley of Crockery Creek by a morainic ridge. On the north and west the confine is sandy and somewhat higher. The soil of the marsh is generally sandy with a few streaks of loam. It was found covered with water by the pioneers, but by an extensive drainage system supplementing and deepening the natural lines most of the surface water now flows away.

Well.—The well is located in the NE. ¼ SE. ¼ sec. 29, T. 10 N., R. 1 W., on property now owned by N. A. Cook, of Moorland. The depth is stated to be 115 feet, but no one was found who knew the record of the strata, though it may possibly be among the papers of the State geologist. The well at first yielded a considerable amount of an inflammable gas, which was collected and burned experimentally by elevating the pipe and reducing the exit. The gas is not so evident now, if it is delivered at all. The water is strongly mineral in quality. The head of the water is about 8 feet above the surface or not far from 100 feet above the lake. The flow is 6 gallons a minute.

It is notable that this well is in the catchment of Lake Harbor and ı the same drainage line with the well near Cloverville. The locaon is somewhat more than 16 miles in a direct line from the outlet of ıake Harbor and about 10 miles from the Cloverville well, and, while he indications are strong that the water of the two wells rises from ntirely distinct strata, yet their locations, height of head, and abunlant flow, suggest the probability that the Lake Harbor and Moorland listricts are continuous.

FRUITLAND DISTRICT.

Topography.—The extent of this district, which is represented by a single well, can only be conjectured. The well is located in the SW. ¼ sec. 36, T. 11 N., R. 17 W. The moraine, which gradually loses prominence, as it extends southward from Whitehall, appears to terminate somewhat abruptly on the same section near the northeast corner. In fact, the moraine probably continues unbroken to the point where it appears in the bluff of Muskegon Lake, but is so low that it is covered by 10 feet, more or less, of sand. The soil is sandy with spots slightly loamy. The surface is a plain interrupted by numerous swells and knolls that appear like very low dunes. The region was originally swampy, and Greene Creek, which flows southward about 4 miles into Muskegon Lake, has its origin here. The elevation is probably between 40 and 50 feet.

Well.—This well was probably driven about 1890 for Mr. John Miller, who then resided on the place. It has since become the property of Jacob Johnson, of Whitehall. When seen several years ago, the pipe stood about 5 feet above ground and the flow of water was very slow, seeming to indicate that the top of the pipe was about at the height to which the water would rise. The depth is stated to be 38 feet.

The existence of a flowing well at the mouth of Greene Creek and another at the source suggests the probability that flowing water can be found throughout the course of the creek, although the great difference in depths of the two wells and in the quality of water, which is decidedly less mineral in the Fruitland well, tend to negative the inference that the so-called Fruitland district is a part of Muskegon Lake district.

CASNOVIA DISTRICT.

Topography.—The region in which the Casnovia wells are found has very pronounced features in the form of morainic prominences of till and gravel. The highest land in Muskegon County lies in Casnovia Township. The railroad track at Casnovia station is 300 feet above Lake Michigan. This elevation is greatly exceeded by hills

in the immediate vicinity and much of the surface in the township is not far from 800 feet above the sea. The depth to bed rock is probably as great as 600 feet in some places and not less than 300 feet at any place. It is extremely improbable, therefore, that a flowing well from any except a local source would be found here. The high land in Casnovia village has been deeply penetrated, in one instance more than 300 feet, without encountering water.

Wells.—A flowing well belonging to Mr. D. Neff is located in the NW. ¼ NE. ¼ sec. 33, T. 10 N., R. 13 W. (Casnovia Township). The well was driven in 1895 by May Doubledee, of Casnovia village. It is 45 feet deep, in clay and gravel, and flows 1 gallon a minute, the yield not having varied appreciably since the well was put in. The head is only about 1 foot. The cost was $45.

Near the northwest corner of sec. 28, slightly more than a mile from the Neff well, Mr. Charles Fraligh has a flowing well, the record of which is not known.

The territory in which these wells are located abounds in natural springs, some of which are remarkable for their size and form the heads of small streams.

SUMMARY.

The flowing wells of the county are distributed as follows: White Lake, Nos. 15 to 37, inclusive; Muskegon Lake, Nos. 1 to 14, inclusive, and Nos. 46 and 47; Lake Harbor, Nos. 38 and 39; Spring Lake, Nos. 41 and 42; Moorland, No. 40; Fruitland, No. 43; Casnovia, Nos. 44 and 45.

No.	Township N.	Range W.	Section.	Part of section.	Owner.	Elevation.	Depth.	Diameter.	When made.	Driller.	Depth.	Character.	Quality of water.	Daily yield.[a]	Temperature.	Remarks.
						Feet.	*Feet*	*Ins.*			*Feet.*			*Gallons.*		
1	10	17	33	SW. ¼ NW. ¼	Central Paper Co., Muskegon.	13	296	8	1903	Central Paper Co.	237	Sand rock	See analysis (p. 36)	P.100,000	11 51.8	Head about 10 feet.
2	10	17	26	SW. ¼ SW. ¼	J. M. Gerrish, Muskegon.	1	237	2	1886	C. C. Jacks, Muskegon.	237		Hard and salty.	Choked.		Choked in upper part of pipe.
3	10	16	30	NW. ¼ NW. ¼	Hackley & Hume, Muskegon.	1	220	1	1889	do	220	Sand rock	do	250	14 57.2	
4	10	16	19	NE. ¼ SE. ¼	Racine Boat Co., Muskegon.	5.5	208	2.5		do	208	do		2,200	12.5 54.5	Head 7.5 feet.
5	10	16	20	NW. ¼ NW. ¼	John Torrent, Muskegon.	1	204		1887	do		do				
6	10	17	22	NW. ¼ NW. ¼	Frank Alberts, Muskegon.	9	240	2.5	1883	do	240		Hard and salty.	2,760	10.5 50.9	Head about 15 feet.
7	10	17	23	SE. ¼ NW. ¼	Dr. J. G. Jackson, Muskegon.	1.5	237	2.5	1901	do	237	Sand rock	do	400	12 53.6	Head about 9 feet.
8	10	16	18	SE. ¼ NW. ¼	Gow & Campbell, Muskegon.	5.5								800	13 55.4	
9	10	16	18	SE. ¼ NW. ¼	do	1	207	3.5	1901	C. C. Jacks	207	Sand rock	Hard and salty.	700	13 55.4	
10	10	16	18	SE. ¼ NW. ¼	do	1								800?		
11	10	16	18	SE. ¼ NW. ¼	do							Sand rock	Salty			Head formerly 7 feet.
12	10	16	19	NE. ¼ SW. ¼	W. H. Dewees, Muskegon.	1										Isolated by destruction of dock and flowing into lake.
13	10	17	25	SW. ¼ NE. ¼	Stewart Hartshorn Co., Muskegon.	5	57	2	1900	Hubert Young, Muskegon.	40 57		See analysis (p. 37)	Closed		Head about 10 feet. Water source local and contaminated.
14	10	16	19	NE. ¼ SW. ¼	Magoon & Kimball, Muskegon.	1				C. C. Jacks				Choked.		"Muck" in pipe.
15	11	18	2	SW. ¼ SE. ¼	United States Life-Saving Service.	5.5	153	2.5	1887	W. H. Dennis, Montague.	153		"Soft"	1,320		Head 8.5 feet.
16	12	17	28	SE. ¼ NW. ¼	L. T. Covell, Whitehall.	2	129	2		Peter Denneau, Montague.	54 129		Salty	480	10 50	Turbid water at 54 feet.

[a] P under "Daily yield" indicates that the well is pumped.
[b] The upper number in temperature column is the temperature as read in Centigrade. The lower number is the same value reduced to Fahrenheit.

Data of flowing wells and of other deep wells having similar source and head, Muskegon County—Continued.

No.	Location. Township N.	Range W.	Section.	Part of section.	Owner.	Elevation.	Depth.	Diameter.	When made.	Driller.	Water bed. Depth.	Character.	Quality of water.	Daily yield.	Temperature.	Remarks.
						Feet.	*Feet.*	*Ins.*			*Feet.*			*Gallons.*		
17	12	17	29	NE. ¼ NE. ¼	Montague village	1		2	1870				Salty	1,440	11.5 52.7	
18	12	17	28	NW. ¼ NW. ¼	do	2	62	2	1878				See analysis (p. 37)	260	12.5 54.5	
19	12	17	28	NE. ¼ NW. ¼	L. T. Covell, Whitehall.	2		2		Peter Denneau.				Extinct.		Water was much liked by horses; pipe probably clogged.
20	12	17	21	SW. ¼ SW. ¼	W. E. Osmun, Montague.	16	37	2					Soft	2,880	9.5 49.1	In public place. Water much sought by people.
21	12	17	21	SW. ¼ SW. ¼	Charles Wyard, Montague.	10	30		1873	J. W. Young, Montague.	30		do	900	9 48.2	Dug with spade; flowing vein found unexpectedly.
22	12	17	21	SW. ¼ SW. ¼	----- Dieske, Montague.	9							do			Said to have checked flow of No. 21 for a short time.
23	12	17	21	NW. ¼ SW. ¼	Charles Rathbun, Montague.	8	18			Peter Denneau.			do	1,080		Stated depth of 18 feet is doubted.
24	12	17	21	NW. ¼ SW. ¼	Herman Runcil, Montague.	10	28		1903				do	1,440		
25	12	17	21	SW. ¼ SW. ¼	Montague village	9	37	2	1902	R. D. Hall, Montague.			do	2,880	11 51.8	
26	12	17	21	SW. ¼ SW. ¼	W. E. Osmun	12	40	2	1900	do			do	1,440	9.25 48.6	
27	12	17	21	SW. ¼ SW. ¼	Montague iron works, Montague.	10	50	2	1904	Frank Coleman, Montague.			do	P. 3,000		Head much lower than in other similar wells in vicinity.
28	12	17	28	¼ line W. ½	Whitehall village	8	67	6	1892				do	P. 50,000	11 51.8	A group of four wells furnishing Whitehall public supply.
29	12	17	28	¼ line W. ½	do	5	110	2	1904	R. Saxton, Whitehall.						Flow slight. Frozen in winter. Shows clay bed of No. 28.
30	12	17	28	SE. ¼ NW. ¼	Carrie Mears, Chicago.	7	82							Extinct.		Robbed by No. 28, about 200 feet distant.
31	12	17	28	SE. ¼ NW. ¼	E. Duttenhoefer, Whitehall.	7								do		Said to have been gradually affected by opening No. 28.
32	12	17	28	SE. ¼ NW. ¼	Mary Reed, Whitehall.	6	96	4.5	1870					720		One of the old wells; date not certainly known.

33	12	17	28	NE. ¼ SW. ¼..	Nufer Cedar Co., Whitehall.	1	57	2.5	1875	Peter Denneau.	....	.....	Soft	100	.....	
34	12	17	28	SW. ¼ SW. ¼..	Eagle Tanning Co., Whitehall.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
35	12	17	33	NW. ¼ NW. ¼.	New York Mill Co., Whitehall.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
36	12	17	33	NW. ¼ NW. ¼.	.....do.....	.....	107	.....	1868	.....	.....	.....	.....	.....	.....	Oldest well in White Lake district according to W. F. Nufer.
37	12	17	28	NW. ¼ NW. ¼.	Boom Co., Whitehall.	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	One of the older wells; date about 1873.
38	9	17	12	SE. ¼ SE. ¼...	Forest Park Association, Muskegon.	25	218	2.5	1885	C. C. Jacks...	218	Sand rock?.	Salty	P.	.....	Head 12 feet below surface.
39	9	16	2	NE. ¼ NE. ¼..	Doctor Gorden, Muskegon.	16	1,600	8	1903	Fred Vance, Geneva, Ind.	340?	Sand rock..	.....do....	23,000	11 51.8	Stated depth seems about 100 feet too great. Head 25 feet.
40	10	14	29	NE. ¼ SE. ¼..	N. A. Cook, Moorland.	95	115	.....	1895	.....	.....	.....	Mineral...	8,640	.....	Formerly emitted combustible gas abundantly.
41	9	16	35	SE. ¼ SE. ¼....	Spring Lake Iron Co., Fruitport.	16	150	2	1883	C. C. Jacks...	.....	.....	Salty	7,200	12 53.6	Flow decreased by leakage. Head 25 feet.
42	9	16	35	SE. ¼ SW. ¼...	Grand Rapids, Grand Haven and Muskegon R. R., Grand Rapids.	26	255	.....	1871	.....	.....	.....	Mineral...	P.	.....	Formerly sold in carloads for medicinal use.
43	11	17	36	SW. ¼ SW. ¼..	Jacob Johnson, Whitehall.	50?	88	.....	.....	.....	.....	.....	.....	.....	.....	
44	10	13	33	NW. ¼ NE. ¼.	D. Neff, Ravenna, R. F. D.	.....	45	2	1895	M. Doubleday	.....	.....	Hard	1,440	.....	Head 1 foot.
45	10	13	28	NW. ¼ NW. ¼.	Charles Fraligh, Canada Corners.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
46	10	16	30	NW. ¼ NW. ¼.	Pere Marquette R. R.	8	2,200	.....	1868	.....	.....	.....	Salty	Choked.	.....	Finally plugged to stop flow.
47	10	16	17	SE. ¼ NE. ¼...	Leon J. Smith, Muskegon.	6	.....	2	1898	.....	.....	.....	.....	.....	.....	Head about 18 feet

WATER SUPPLI

By M

TO

Oceana County borders o
eastern side of the lake, the
The southeastern part is occ
White River flows. North o
morainic system about 12 mi
a course north of east, the vill
its inner border and New Er

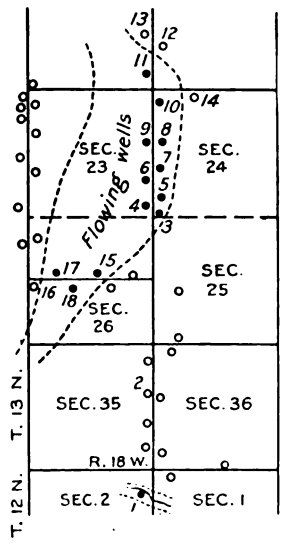


FIG. 4.—Sketch map of Flower Creek artesian district, Oceana County.

bor
part
nort
que
nort
are
Mic
nort
hav
wat
ext
limi
tem
feet
gan
300
app
as i
The
full

Numerous wells in the high
water there shows the very
in recesses along the border
traversing it.

FLO

FLOWE

The Flower Creek district
13, and 26, T. 13 N., R. 18
and 24. It is situated in th
where Flower Creek post-off
5 or 6 miles northwest of M
the district (see fig. 4) are l

the creek, some 30 feet or more above it. Back of the terrace, on both the east and the west, the morainal hills rise to a considerable height. The statistical data relating to the wells are presented in the table below. Sufficient agreement of depths is shown to indicate for the northern wells at least (Nos. 3 to 11) a uniform source of supply from a water-bearing layer sloping somewhat rapidly to the northwest and drawing its water from the morainal hills to the southeast. Of the three wells (Nos. 15, 17, and 18) at the southern end of the district, Nos. 15 and 18, or the two easterly wells, yield a medium hard water containing iron, while No. 17, although drawing its supply at the same depth as No. 18, gives a soft water free from iron. This probably indicates a separate source of the water in the different wells, due either to the presence of two distinct beds or to a single bed receiving additions of water from both the east and the west, the former hard and irony and the latter soft. It seems probable that Nos. 15 and 18 are not on the same vein as Nos. 3 to 11, as the flow under similar conditions is many times greater. The source, however, as in the case of the latter, is in the hills to the southeast. The Charlotte Smith well (No. 1) belongs to a separate and very limited district occurring along the creek bottom in secs. 1 and 2, T. 12 N., R. 18 W.

Wells of Flower Creek artesian district.

No. on fig. 4.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Feet.		*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	Charlotte Smith [a]		611		2	Deep.		+ 1	1/16	56		Slight iron.
2	Unknown				2	30						
3	Jacob Conrad [b c]	William Dennis	649	1890	2	103	546	+ 4	¾	49½	Quicksand	Iron; very hard.
4	Conrad & Fuller [c]	do	638	1901	2	107	531	+ 7	1¼	49¾	do	Iron; medium hard.
5	J. H. Conrad [d]	Dennis	615	1891	2	105	540	+ 0	½		do	Do.
6	George Kinkie	Dennis (?)	640	1884	2	129	520	+ 5	½	50½		Slight iron.
7	Peter Delemater [e]	Peter Dennis	649	1872	2	112	537	+ 5	½	49¾	Sand and gravel	Iron; medium hard.
8	Aug. Lohman [f]	Sykes	654	1895	2	130	524	+ 2	¼		Gravel	Iron; hard.
9	George Kinkie [f]	Dennis (?)	649		2	130	519	+ 3	¼			Medium hard.
10	William Grumm [g]	Sykes	663	1886	2	139	524	+ 2	¼		Sand	Iron; medium hard.
11	Peter Shirtum [h]	Dennis	673	1886	2	180	493	− 3			Quicksand	No iron; hard.
12	Joe Schailler		678		2	100+	578	− 3				
13	Carl Strohl [i]		685		2	150+	535	− 9				
14	Unknown		685		2	90	595	Many.				
15	J. T. Fohlbrook	Dennis	635	1899	2	117	518	+ 5	27	49¾	Quicksand	Iron; medium hard.
16	Eagle [j]		600		2	40	560	− 20				
17	Richard Fohlbrook	Dennis	630	1899	2	150	480	+ 4	½			No iron; soft.
18	Pfund	do	635		2	153	482	+ 3	10	49¾	Sand	Iron; medium hard.

[a] Located on a low terrace, less than 10 feet above the creek, and has flowed a tiny stream for many years, indicating a very close-textured water horizon. The outlook for wells in that vicinity is therefore not good.

[b] Encountered clay all the way to the quicksand except through a few feet at the top. Flow varies with the season.

[c] Used in a creamery and in boilers, the latter requiring cleaning every two months. Well reduced to one-half inch. Soil, 2 feet; clay, 5 feet; alternating clay and sand to bottom, with water between 35 and 60 feet. No decrease of supply. A curious statement is made that the wells on the west side of the road do not vary in flow, but that those on the east fluctuate with the level of a swamp 2 miles east, but it is doubtful if the fluctuation is anything more than a coincidence.

[d] Formerly flowed, but now piped into barrel set in ground and supplying the barn at lower level by an overflow pipe.

[e] First flowing well of the district. Nothing but clay was found except a thin water bed at 70 feet and the sand and gravel at the bottom. The water at 70 feet rose but little.

[f] Decreased since first sunk; show seasonal variations of flow.

[g] Now pumped.

[h] Ceased to flow in dry spell about 1895, and has not flowed since, possibly because of the clogging of the well.

[i] On a knowl in a rolling morainal country, some of the hollows being low enough to give a flow if the same water bed which occurs in the wells to the south is present. They have not therefore been tested.

[j] No attempts to obtain flow. Houses along road bordering secs. 23 and 26 on the west have only shallow wells, mainly less than 40 feet.

ater of the Flower Creek wells carries a much larger amount han most Michigan waters, but is of about the average hard- Vells Nos. 15 and 18 are highest in iron and lime. Wells Nos. carry somewhat less iron, but are about as hard. No. 17 is on and unusually soft.

robable that wells drilled anywhere along the road between nd 11 would obtain flows, but they would not be large, since ly, as indicated by the seasonal fluctuations, is limited, being l utilized by the present wells. Wells drilled some distance he road and nearer the center of the district would also prob- ain flows. The best wells will perhaps be found at the south- of the district, where the supply seems to be more abundant. probable that the flowing area will be extended much to , as the land begins to rise rapidly within a short distance, not impossible that deep wells east of No. 15 and not far ould obtain good flows. The water bed at the Charlotte ell (No. 1) seems to be too close textured to give up water hence the prospects for satisfactory flows in this vicinity are

SHELBY DISTRICT.

helby district in western Oceana County is in secs. 30 and 31, , R. 17 W., and secs. 25 and 36, T. 14 N., R. 18 W., and is miles southwest of Shelby village. It lies along the east-west ear the south line of secs. 25 and 30, and is bordered by high

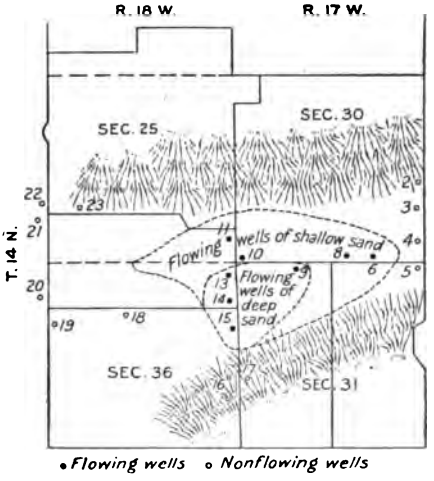


FIG. 5.—Sketch map of Shelby artesian district, Oceana County.

l hills on both the north and the south. The creek has cut its to a considerable depth below the rolling terrace on which the located. The character of the wells surrounding the district in the table given below. (For locations, see fig. 5.) With or two exceptions, every house in the district has a deep well ows. All are stopped down to small pipes.

Wells of Shelby artesian district.

No. on fig. 5.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Feet.		*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	*° F.*		
2-4	Several [a]		700		2	All shallow.					Sand	Soft.
5	F. Perkins [b]	Wm. Dennis	705		2	112	593	−5			Sand or gravel	Hard.
6	John Lewis [c]	do	685		2	115	570	+18	8	48½	do	Do.
7	I. Floyd [d]	J. Round	677		2	125	552	+Many.	18	48¾	do	Do.
9	G. O. Anderson [e]		685	1891	2	174	511	+15	Many.		do	Iron; hard.
10	A. Anderson [f]		675	1894	2	125	550	+Several	Many.		do	Hard.
11	John Anderson [g]	Wm. Dennis	675	1892	2	100	575	+6	Several.		do	Do.
13	Geo. Nelson [h]	do	667	1894	2	220	447	+6	10	49½	do	Iron; medium hard.
14	John Josephson [i]	Chas. Denno	657	1890	2	182	475	+20			do	Iron; hard.
15	Moses Burke	do	666	1893	2	180	486	+20		47¾	do	Iron; medium hard.
16	S. E. Lewis	(*j*)	687	1895		50	637	−Few.			do	Hard.
17	L. Lewis [k]	(*j*)	693			20	673	+0			do	Do.
18	P. J. Esperhaug		650	1892	2	55	595	−0			do	Do.
19	H. Hendrickson		655			50	605	−0			do	Do.
20	Andrew Myrmal		640			40	600	−0			do	Do.
21	Thos. Kelley		680			12	668	−8			do	Medium soft.
22	Schoolhouse		665			85	580	−12			do	Hard.
23	B. Karstad		660			80	580	−0			do	Good.

[a] All shallow, being simply short pipes driven into the sand and other material, and using suction pumps.
[b] Small flow, a mere drizzle at 90 feet, but lost it on going deeper.
[c] Used for the irrigation of strawberries.
[d] Started with a small flow, which rapidly increased. Sand 5 feet, hardpan 3 feet, sand 5 feet, quicksand 47 feet, clay 65 feet.
[e] Piped to a residence, a house across the street, a barn, and a watering trough in the road.
[f] Under cover in a house.
[g] Threw a 2-inch jet 5 feet high at first, now piped to residence, milk-house, and barnyard.
[h] In sinking well 100-foot length of pipe sunk under its own weight and disappeared in the soft gravel.
[i] In clay for practically entire depth.
[j] Dug.
[k] Went 20 feet without getting water, but during a thunder shower, when the workmen were away, the water broke through from below, filled it to the top, and overflowed. The breaking through was possibly due to the lessening of the atmospheric pressure during storm and the weakening of the stratum below which the water was held under pressure.

the records of the wells are studied two interesting points are evi- : (1) Wells Nos. 9, 13, 14, and 15 are much deeper than the rs of the district, and (2) the waters of these wells contain much ,while the others do not. Constructing a section from the records fig. 6) we have not only evi- :e of two distinct water beds g the township line, but evi- :e of slopes toward the valley oth directions, presumably due ıe bending of the beds into a gh, which probably accounts in for the unusually large flows. he water of the Shelby district

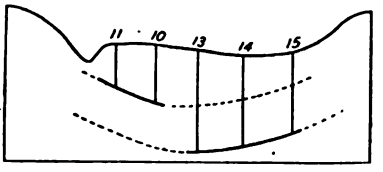


FIG. 6.—Diagrammatic section across Shelby artesian district from north to south, showing upper and lower artesian horizons and trough-like structure.

nsiderably softer than the average Michigan water, and is there- unusually satisfactory for domestic purposes. There is a very ıt amount of iron in the waters from the upper sand, but about e times as much in the lower sand. Partial analyses of the John lerson water, representing the upper sand, and the Nelson water, resenting the lower sand, are given on page 91.

he area in which flowing wells may be expected is outlined in fig 5 49). This area might be extended slightly by wells at low points

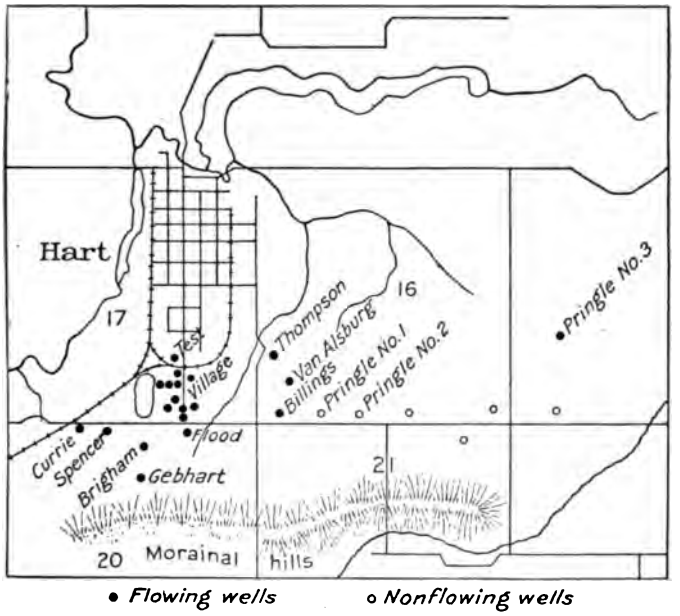


FIG. 7.—Sketch map of Hart artesian district, Oceana County.

ıe valley to the east or to the west, but not to the north or to the ı, as the land rises steeply in these directions. There is sufficient r in the district to supply the needs of a much greater number of le than now live there.

HART DISTRICT.

Hart, the county seat of Oceana County, is located on a somewhat irregular sloping terrace. At the north edge of town it is cut by a valley occupied by ponds and a large creek some 30 feet below the railroad. To the south, or away from the creek, the surface rises gently for three-fourths of a mile or more to the foot of morainal hills of some height (see fig. 7).

The shallow-water supplies at Hart have been found to be irregular in depth and in amount, but in general only small amounts of water have been obtained. At present very few shallow wells are used, nearly every house at the upper end of town having either a flowing well or a deep well pumped by windmill, while in the town itself nearly all supplies are obtained from the public water system (p. 59), which furnishes an abundant supply from an unusually complete system of mains. The location of a portion of the wells is shown in fig. 7, while data relating to these and to others not shown on the figure have been compiled into the following table:

Wells of Hart artesian district.

Owner.	Driller.	Elevation of well.	When drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*		*Gals.*	°*F.*		
Robt. Currie	.....	747	1900	2	110	637	+0	.....	....	.....	
Ed. Spencer[a]	.....	736	1903	2	135	654	0	.....	....	.....	
B. Gebhart[b]	.....	742	1901	2	160	582	−1½	.....	....	.....	
S. C. Brigham[c]	Joe Mull.	730	1904	2	100	630	+18	36	49¾	Sand, gravel	Hard.
J. K. Flood[d]	.....do..	730	1900	3	117	613	+9	Many.	....	.....do.....	Medium hard.
Village (see p. 59)	Jacks...	730	1895 1898	6	112 152	578 618	+20	Many.	....	.....do.....	Do.
John Billings[e]	Joe Mull.	710	1901	2	107	603	+20	Many.	....	.....	Hard.
Van Alsburg[f]	.....do..	700	1900	2	150	550	+40	Many.	....	Sand, gravel	Iron; hard.
H. B. Thompson[g]	.....	690	.....	2	.....	.....	+2	2	49½	.....	
F. M. Pringle No. 1[h]	.....	720	.....	2	120	600	−0	.....	....	Sand	
F. M. Pringle No. 2	.....	715	.....	2	40	675	−0	.....	....	Clay	
F. M. Pringle No. 3[i]	.....	710	.....	2	65	645	+4	.....	....	.....do.....	

[a] Obtained water at 82 feet and below, but on reaching depth of 135 feet it was all lost in the hardpan at that point.
[b] Originally about 50 feet deep, but deepened to 160 feet on account of failure of the supply.
[c] Shallow water was encountered above clay at 40 feet; flow from the lower horizon is a strong one but it is restricted to a small pipe; not affected by the village wells.
[d] No water above the main flow except at the surface. Piped to barn, house, and watering trough. There are several hydrants on the place to which fire hose and hose for sprinkling can be attached. The supply is said to be affected by the town wells.
[e] Threw jet to top of porch 15 feet high when first sunk.
[f] Located near south line of block 137, several hundred feet south of a slaughter house, and one-eighth of a mile from the road. Head tested to height of 40 feet; a 2-inch jet was thrown 8 feet. Much sand and gravel was brought up by the water at first. Soil 3 feet, hardpan 1 foot, sand 15 feet, clay 127 feet sand and gravel 4 feet. Water is piped to barn, slaughterhouse, and residence and used for all purposes. No effect by the town wells is noted.
[g] Formerly owned by Mr. Waller; is small well, but is used by 5 families.
[h] Encountered only sand.
[i] Penetrated only clay until near the bottom.

The deepest well at Hart is the test boring made just north of the railroad opposite the warehouse, at an elevation of about 730 feet (see p. 59), which was drilled by Mr. Jacks to a depth of 412 feet.

stone was encountered at 371 feet and the bottom of the well in shale. The vein furnishing the flows in the vicinity was d through without stopping, and the final well furnished little r. A boring known as "Henman's boring," said to be located 40 feet lower than the preceding and to be 200 feet deep, is rted, but could not be located. Four wells are reported at the house: One is said to be 171 feet deep and flows; the other three noted in connection with the waterworks on page 59; the rials penetrated were: Clay 5 feet, sand 25 feet, clay with peb- to bottom. The water was from sand and gravel, surface sup- being encountered at 7 and 20 feet. These wells were drilled 02 and are 4 inches in diameter.

ginning with the Brigham well and going north to the ware- e there is a very regular increase in the depths of the wells. This ates a uniform source of supply from a bed tilting gradually ıward. The Gebhart well, if its depth is correctly stated, draws ıpply from a bed probably 75 feet lower, while the Currie and cer wells seem to draw from a higher horizon, although if the furnishing supplies to the waterworks wells rises sufficiently pt it may be present at the depths indicated by the two wells ioned. The Billings and Van Alsburg wells probably draw the same bed, which possibly is the same as that at the water- s. The Thompson well, judging from its small flow, is probably a higher horizon, although its depth could not be ascertained. horizon at the Pringle No. 3 well can not, with the present mation, be correlated with any of the water beds nearer town.

ıe water carries a small amount of iron, a considerable amount lt, and is of average hardness. A partial analysis is given in the on page 91.

ıe conditions, while sufficiently variable to make prediction of exact depth at which water will be found uncertain, appear to nusually favorable to artesian flows, which can probably be ined almost anywhere on the lowlands to the north of the morainal indicated in fig. 5, where the altitude is less than 730 feet (or of the Brigham well), and when the distance is not more than half to three-fourths mile from the hills. At distances greater than flows are less likely because of the liability of the water-bearing ıs to pinch out. The depths of the wells will generally vary from to 175 feet, although it may be necessary to go deeper in some s. If the well is properly sunk, the flow should be large.

CRYSTAL VALLEY DISTRICT.

he village of Crystal Valley, in northern Oceana County, is located a terrace bordering a small stream, to the north and south of which morainal hills rise to a considerable height. (See fig. 8.) There is

only one well (No. 1) actually flowing at the point where drilled although several (Nos. 2, 3, and 4) rise nearly to the surface, and one (No. 5) is piped sidewise to flow at a slightly lower level. Statistical data relating to the wells at this point are given in the following table.

Wells of Crystal Valley district.

No. on fig. 8.	Owner.	Driller.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Ft.*	*Galls.*	°*F.*		
1	H. C. Lockwood	S. Cree	712	1898	2	97	615	+11	5	[a]50½	Gravel.	Iron.
2	Mrs. Linn Kinney	.....	720	.....	2	40	680	− 2	Many.	....		
3	L. C. Beadle	L. C. Beadle.	720	1898	2	16	704	−15	.....	....	Sand	Soft.
4	J. W. Perkins	S. Cree	725	1899	2	126	599	− 2	.....	....	Gravel.	Iron; medium
5	R. W. Kittridge	do	730	1899	2	87	643	− 2	1	[a]50½	do	Soft.

[a] Both measurements of temperature were made after the water had flowed through a pipe of some length and are possibly one-half degree too high.

An examination of the table shows that there is no general water bearing bed, unless, as is very likely the case, the Lockwood and Perkins wells draw from the same horizon. If this is so, its slope is decidedly to the south, and the source of supply is doubtless in the hills to the north. The water of the Kinney well, although having approximately the same head as the others, is not from the same bed. The Beadle well is inserted simply as a type of the shallow wells. The Kittridge well may possibly be from the same horizon as the Perkins and Lockwood but in the absence of wells in the mile stretch intervening this can not be certainly determined.

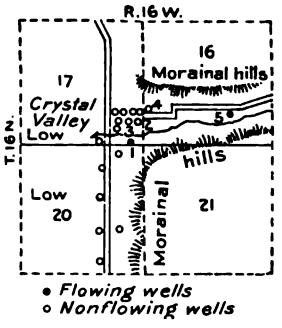


FIG. 8.—Sketch map of Crystal Valley artesian district, Oceana County.

The deep-well water is of about the average quality. It tastes of iron, is hard, and gives considerable scale. The supplies from the surface wells are considerably softer.

Flows can probably be obtained at almost any point which is not more than 6 or 8 feet above the level of the creek. The head is sufficient to give flows on the terrace on the south side of the stream but not on the north. The volume is such that hydraulic rams attached to wells at creek level would pump sufficient water to the houses for domestic supplies.

ELBRIDGE DISTRICT.

The Elbridge district, at present represented only by a single flowing well, is located a few miles east of Hart along the broad valley bordering the streams in the northern portion of secs. 8 and 9,

5 N., R. 16 W., the supply coming from the high morainal hills bout Elbridge settlement, one-half mile to the south. (See fig. 9.)

The flowing well (No. 2) is owned by Isaac Timmons. The data re as follows: Altitude, 712 feet; drilled in 1901; depth, 93 feet; ater from blue gravel; flows at +4 feet; tested to 18+ feet; yield, gallons a minute; temperature, 49½°. The materials are: Sand, 35 et; clay, 55 feet; gravel, 3 feet. The well is located several feet bove the level of the creek bottoms.

At the mill one-half mile east and a little north of Timmons a well ailed to get water on the flats at 100 feet, although most wells in the icinity (as No. 1) get abundant surface water. Near by are large ulphur springs, which form a considerable stream and deposit a hite coating of sulphur. A deep well (No. 3), one-fourth mile north f Timmons, failed to get a flow, which was to be expected, as it is nany feet higher. A well at the corner blacksmith shop in Elbridge No. 4) went through 20 feet of sand and 40 feet of clay into water-earing gravel at 60 feet, the water rising to within 16 feet of the surface. Surface water vas obtained at the store on the opposite ide of the road at 16 feet. A well 60 feet leep in the hollow back of the blacksmith's nd 20 feet lower got water rising to within foot of the surface. Gus May, 2 miles ast and one-half mile south of Timmons well, drilled 92 feet and obtained about 1 uart a minute. The well was drilled by Hardy. The wells in the morainal hills are enerally 50 to 100 feet deep.

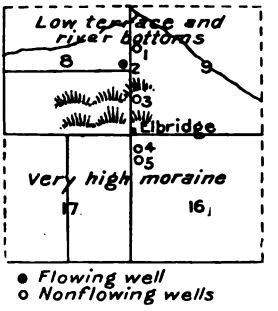


FIG. 9.—Sketch map of Elbridge artesian pool, Oceana County.

The water of the Timmons well is of average quality as regards iron and lime. For partial analysis see page 91.

The only good prospects for flows are along the flats of the creek bottoms adjacent to the base of the morainal hills. The majority of wells sunk at such locations to 100 or 150 feet would probably be successful, although an occasional failure is to be expected, as was the case at the mill. Abundant water supplies, however, are generally to be had at slight depths, and will doubtless prove satisfactory as long as the country is not too thickly settled.

TIGRIS DISTRICT.

The Tigris district is a short distance east of Hart. Like the Elbridge district it has at present only one flowing well, although the drilling of others is contemplated. The conditions are illustrated in fig. 10. Along the north and east side of sec. 13, T. 15 N., R. 17 W. the land rises into morainal hills of considerable height, while the remaining portion of the section is moderately flat. Along the base

of these hills occur a considerable number of springs, a few of which have formed mounds of silt of some size.

It was near the base of the hills that the Amos Relinger well was sunk in 1902. It is a 2-inch well, 115 feet deep, and obtains its water from gravel. The water, which will rise 15 feet or more, is piped into the house. The yield is 12½ gallons a minute. It tastes slightly of iron and is medium hard, though giving little scale.

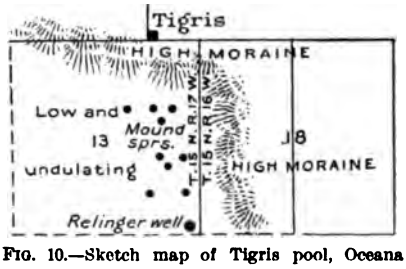


FIG. 10.—Sketch map of Tigris pool, Oceana County.

The water of the Relinger well doubtless comes from the east, although in the northern portion of the section supplies may also be received from the north. It is probable that deep wells almost anywhere along the base of the hills would obtain flows.

LATTIN DISTRICT.

The postmaster at Lattin reports the wells in the neighborhood to be from 30 to 250 feet deep, the largest supplies being at about 100 feet, which is the common depth in the vicinity. The water in both the shallow and the deep wells is hard. He states that some flowing wells are obtained at the surface without pumping.

WEARE DISTRICT.

This district is located in secs. 34 and 35, T. 16 N., R. 17 W., a mile or two west of Weare and 3 or 4 miles northeast of Hart. The flowing wells are on a gently rolling slope pitching away from the high moraine hills in the northern portion of the sections (fig. 11). The ground is still lower to the south, but because of lack of persistence of the water bearing beds and the loss of head no flows are obtained. Data relating to the wells are given in the following table:

Wells of Weare district.

No. on fig. 11.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Gal.*	°*F.*		
1	Several		750		2	90	660	−75			Sand and gravel.	Slight iron moderately hard.
2	Victor Symonds	Joe Mull	690	1899	2	58	632	−2	¼		Gravel	Do.
3	H. Warmuskarker	do	690	1900	2	58	632	−2			do	Do.
4	Unknown		680		2	(a)		(b)			Sand	Do.
5	John Lipp	Joe Mull	670	1897	2	128	542	+5	¾	49¾	Gravel	Do.
6	Henry Baker		665		2	6	659	−1			do	Do.
7	John Lipp, jr	K. Clay	662	1904	2	428		None.			Clay	Do.
	do	do	662		2	150	512	−15			do	Do.

a Shallow. b Several feet below surface.

The wells at the crest of the hill (No. 1), of which there are several, get plenty of water, although it rises but little. The Victor Symonds and Henry Baker wells are piped sidewise to lower ground to give flows. The surface material is sand to a depth of 15 to 20 feet, after which clay is struck, which continues, with the exception of a few thin sandy beds, to a depth of at least several hundred feet. Several attempts to obtain water were made at the John Lipp, jr., place. Except for 10 feet of sand at the top all was clay to the bottom of the deepest well at 428 feet. Another well a few feet away was sunk to 150 feet and found water at the bottom, which rose to within 15 feet of the surface, but the clay from which it came so clogged the pipe that the well could not be used. Another well 135 feet deep gave similar results. These wells are said to have been located by means of the "switch" or divining rod and are notable failures.

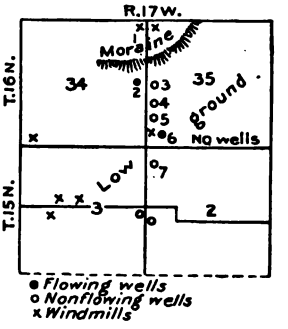


FIG. 11.—Sketch map of Weare pool, Oceana County.

The water is low in iron and of about average hardness. A partial analysis is given on page 91.

The prospects of additional flows in this locality are poor, because of the presence of a great thickness of clay with very few porous seams capable of carrying water. Doubtless such seams occur locally, but their location can not be foretold.

FERRY DISTRICT.

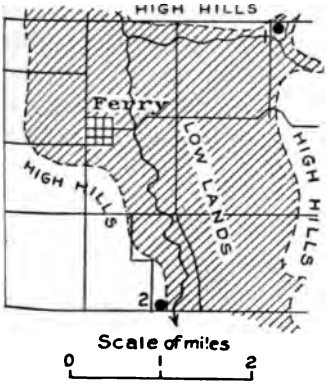


FIG. 12.—Sketch map of Ferry district, Oceana County

This is not a district in the proper sense, as the two flowing wells in the vicinity are several miles apart and of diverse occurrence. The name is simply given for convenience of discussion.

The locations of the wells are shown in fig. 12.

Well No. 1, the James Osborn well, is located on a flat lying between the high morainal hills which rise along the northern edge of sec. 23, T. 14 N., R. 16 W., and the westward flowing stream one-fourth mile to the south. The elevation is about 950 feet, diameter 2 inches, depth 90 feet. The materials were alternating clay, sand, and gravel, with some water for 40 feet, then clay for 50 feet to the water-bearing sand at the bottom. The well ran a small stream for a year and suddenly the flow changed to a strong stream, as if the water had broken through a *hitherto impervious* layer. It was drilled in 1900 by

Charles Cushman. The flow is through a ⅛-inch perforation in tl cap 3 feet above the surface, but the water would probably ris siderably higher. Shallow waters are readily obtained in the v and no other deep wells have been sunk. The water is unusual for Michigan and has but little iron. For partial analysis see pa

Well No. 2 was sunk in 1898 for B. A. Wiswell by Charles Cus driller. It is located on a slope between the stream flats in the sec. 34, T. 14 N., R. 16 W., and the morainal hills rising immedia the west. Its altitude is probably about 955 feet. The we inches in diameter, 78 feet deep, and penetrated 8 feet of clay lo feet of quicksand, and 60 feet of clay. The flow is three-fourtl gallon a minute at 6 feet, but will be nearly as strong 10 feet abo surface. It has no taste, but has slight sulphur odor. It form scale. The flow increases before a storm. The temperature is No other wells in the vicinity go deep enough to obtain flows.

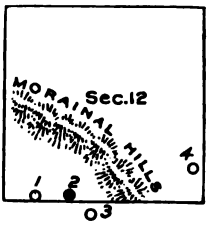


FIG. 13.—Sketch map showing flowing and adjacent wells, Greenwood district, Oceana County.

The lowland area bordering the stream ing through Ferry and the position of th dering highlands are indicated in fig. 12. hills are high and sandy and present ideal ment conditions. The two deep wells have been sunk near its edge have bee cessful in obtaining flows, and it is probabl similar flows could be obtained elsewhere the border and probably for a distance o fourth to one-half mile distant from the m It is possible that flowing wells might be even in the middle of the lowland area. A however, because of the abundance of sl water supplies, no deep wells have been sunk in this region. At the wells are all probably under 30 feet in depth. The materia very variable, but some clay is reported. It is probable that at a depth of 100 feet or less would be sufficient to give flows.

GREENWOOD DISTRICT.

The name of Greenwood Township is applied, for want of a l one, to the district containing the wells about 3 miles southw Hesperia in sec. 12, T. 13 N., R. 15 W. and vicinity, the locat which is shown in fig. 13.

The flowing or nearly flowing wells are located near the bas series of morainal hills of some height bordering the flats in the s west corner of the section. A few details regarding the wel given in the accompanying table:

Wells of Greenwood district.

Owner.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
	Feet.		*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
Unknown	950	.....	2	40	920	—16	.....	.....	.....	
Isaac Bronstrom	960	1898	2	46	916	+18	4	48½	Gravel.	Iron; very hard.
J. Donahue	970	.....	.....	71	899	.....	.....	.....	.....	
Unknown	1,000	.....	2	200	800	— 0	.....	.....	.....	

The Bronstrom well was driven 28 feet and drilled the rest of the ıy in "pebble rock," possibly cemented gravel. It may be, how- er, that bed rock was actually encountered, as rock is reported in her wells in the region and bowlders are unusually numerous a ort distance farther west. The casing extends only 36 feet. The iginal flow was 8 gallons a minute, but the well is now stopped down about half. The Donahue well originally flowed a small stream feet above the surface, but ceased a few hours after the Bronstrom ell was opened, thus furnishing an interesting case of a higher well fecting the supply of a lower well on the same vein.

WATERWORKS.

HART.

The Hart waterworks are located on a terrace at the southern edge the town, 45 feet or more higher than the lower or northern edge ıd 75 feet higher than the creek. (See p. 52.) The supply is om 6 flowing wells 112 to 152 feet deep, the individual depths being 52, 138, 125, 116, 114, and 112 feet. The altitude of the wells is out 730 feet, which would make the elevation of the water bed 578, 12, 605, 614, 616, and 618 feet, respectively. Three of the wells ere sunk in 1895; the others in 1898. Mr. Jacks was the driller. ıe diameter of the wells is 6 inches; head, 16 feet; supply, large; mperature, 49¾°; no taste; slight scale; medium hardness. For ırtial analysis, see page 91.

The water flows directly from the wells into the pipes, the pressure ing about 8 pounds at the station in winter. In summer this is duced to zero. The capacity of the pumps is 750,000 gallons a day, ıt 500,000 gallons is the greatest amount so far used, this draft low- ing the water to 15 feet below the surface. There are 30 fire hydrants d about 400 taps, supplying somewhat over 1,000 people. The sup- y is not as large as could be desired and a reservoir is talked of.

An additional supply is derived at times from three wells at the ıght warehouse, which are owned by the village, but leased with the ilding. They are 4 inches in diameter and 157, 164, and 166 feet ep.

SHELBY.

Shelby is located in a valley between hills of morainic drift, the elevation at the railroad station being 807 feet. The hills are 100 feet or more higher. The wells in town vary from about 45 to 120 feet in depth, the most common depth being between 50 and 100 feet. The largest supplies are said to be obtained at about 70 feet. The water was mostly quite hard.

The deepest well in the town is at George Getty's mill, at an elevation of 807 feet. The depth of the well is 516 feet. Near the bottom the pipe struck a stone and was deflected, making it necessary to abandon the well. Very little water was obtained, and it did not originally rise near the surface, but it was thought that a flow was passed through on the way down. The well was capped and allowed to stand for some time. On taking the cap off the well flowed weakly but ceased soon after. An attempt was made to dynamite the pipe at the supposed water horizon, but the shot was exploded by a blunder at 50 feet and the well was ruined. It is not impossible that flow may be obtained along the valley near Shelby.

The public water supply is derived from two wells located at the electric-light and water plant on the east side of the village and owned by the town. The wells are 125 feet deep, but the water rises within 70 feet of the surface and is pumped to a circular brick reservoir on the hill east of and above the waterworks, and from there is distributed. It is under a pressure of 72½ pounds. The daily supply is usually from 100,000 to 200,000 gallons.

PENTWATER.

Pentwater, in northwestern Oceana County, is located on a sand flat about 5 to 15 feet above Pentwater Lake, an inclosed bay connected with Lake Michigan by an artificial channel. The country back of the town rises more or less gradually to a broad terrace 1 feet or more above the lake level.

The wells in town are generally very shallow, extending to lake level or less, 16 feet being about the average depth. The material near the shore is mainly sand; farther back there are some thin clay seams. In a well sunk by Sands and Maxwell at the corner of Hancock and Fourth streets to a depth of 187 feet, the material was all till below the upper 15 to 20 feet, which was sand. The well did not flow.

The public supply is obtained mainly from 40 to 45 wells, 8 to feet above lake level, situated along Hancock street between Second and Third, and west along the latter streets for half a block or more. The depths are from 16 to 24 feet and the diameter from 2 to 4 inches. Three-foot strainers are used with the 2-inch pipe and 5-foot strainers

with the 4-inch pipe. Strainers 4 inches in diameter were formerly connected with 1½-inch pipes, but the flow was so sluggish through them that they soon became clogged. The strainers now used are only slightly larger than the well pipe and much less trouble is experienced. The water, though not tasting of iron, deposits a reddish sediment. There is also a distinct organic taste, variously attributed to lack of proper flushing of the pipes or to the drawing in of lake water when pumping is excessive. It should be noted, however, that the taste is less conspicuous at the wells than in the more remote parts of the system.

While the water is only moderately hard and there is nothing in its analysis to indicate any difference from other Michigan waters (see analysis, p. 91), the supply can not be regarded as an entirely safe one. There is no clay or other impervious layer to prevent the seepage from privies, cesspools, etc., from passing directly downward and polluting the ground waters, especially near the surface. It is true that natural sand acts to a certain extent as a filter and through its bacteria tends to break down the dangerous substances present, but when new polluting matter is constantly being added a time will come when the ground is saturated and the ground water inevitably polluted. The remedy ordinarily would be to go deeper, where the water would be from a more remote and less thickly settled source. At Pentwater, however, glacial till, which carries very little water, is encountered a few feet below the surface. Wells sunk above the town on the east would give safe supplies, but it is not known whether sufficient volume could be obtained there. The next best source would doubtless be from wells across the harbor on the Lake Michigan shore or even from that lake itself.

The waterworks are owned by the village, but are leased to the Oceana Electric Light Company (B. C. Lindly, manager), which for the sum of about $165 per month supplies the town with water and twenty 1,000 candle-power lights. The franchise is for ten years. The average daily supply is said to be 250,000 gallons, but this can be increased to 600,000 from the wells alone, and to 1,000,000 if the lake is drawn upon. The water is distributed from a trunk main, 10 inches in diameter, along Hancock street, and by various smaller laterals. The ordinary pressure is 40 pounds, which can be greatly increased in case of fire.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table gives data on village supplies:

Village supplies in Oceana County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Allen Creek	No returns						
Cabmoosa	Driven wells, creeks	12	205	100	100	− 0	Small.
Crystal Valley	Driven wells, creeks, and artesian wells.	25	100	50	100	± 0	Do.
Elbridge	Driven wells (artesian wells near).	10	80	50	75	−40	None.
Ferry	do	12	30	25	25	− 8	Medium.
Gale	Driven wells	10	60		60	− 0	
Hart	Driven wells, artesian wells	98	197	175	175	+30	Large.
Hesperia	Driven wells, artesian wells, springs.	15	175		175	+ 35	Medium.
Houseman	Driven wells	30	104	90		− 0	Do.
Klondike	No returns						
Lattin	Driven wells	30	250	100	100	± 0	
Mears	do	32	112	50		− 0	
New Era	do	16	100	25	25	− 0	Small.
Peachville	No returns						
Pentwater	Driven wells	15	50	25	25	− 0	Medium.
Rothbury	do	26	30	28	28	− 0	
Shelby	Driven wells (artesian wells near).	44	121	50	70	− 0	Large.
Tigris	No returns (artesian wells near)						
Wagar	do						
Walkerville	Driven wells	6	90	60	60	− 0	Small.

WATER SUPPLIES OF NEWAYGO COUNTY.

By Myron L. Fuller.

GENERAL STATEMENT.

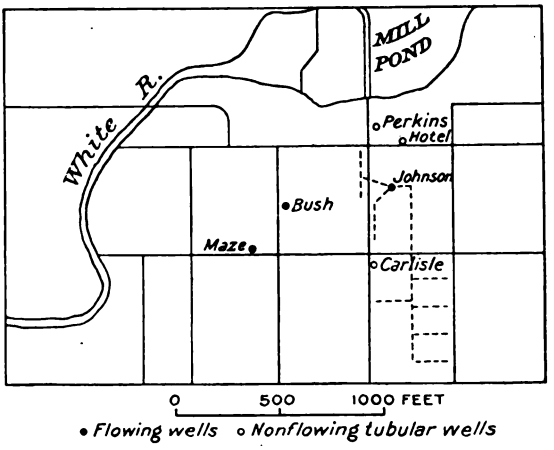
Newaygo County is situated immediately east of Oceana and Muskegon counties, about midway of the western side of the Southern Peninsula. It was covered by the Lake Michigan glacial lobe, at whose junction with the Saginaw lobe is in an interlobate moraine which occupies the eastern part of Newaygo County and the western part of Mecosta. This moraine has points within the county whose altitude exceeds 1,200 feet, and its general elevation is more than 1,000 feet. It is traversed by Muskegon River, which leaves it on the west at about 700 feet above tide and descends to about 600 feet at the southwest corner of the county. West of the interlobate moraine is a gravel plain several miles in width occupying much of Home, Monroe, and Wilcox townships and parts of Everett, Brooks, and Grant townships. The western half of the county is occupied by prominent morainic tracts, which are interrupted by a network of valleys, which served as lines of glacial drainage, and which are now traversed by the South Pere Marquette and White rivers and their tributaries and by Muskegon River. Flowing wells have been found at Newaygo, in the valley of Muskegon River, at Hesperia, in the val-

White River, in and near Fremont, on a plain on the western r of a prominent moraine, and near Grove, in the southeastern ›f the county on the western border of the interlobate moraine. ·riter has examined all but the last of these districts and that is ›sed by Mr. Bowman. As in Oceana County, wells on the ele- morainic tracts are often 100 to 180 feet in depth with but little : water. Much of the county is unsettled, and its water sup- ıre thus only partly developed. The village supplies as well as ›wing wells are discussed below.

FLOWING WELLS.

›re are four artesian-well districts of some importance in this y—at Hesperia, Fremont, and Newaygo, and in Ensley and townships. Several scattered flowing wells are also reported a number of other points. A small district southwest of Hes- is described under Oceana County.

›peria is located on the boundary between Newaygo and Oceana ies, the county line passing through the principal street. Two : three wells are located in Oceana County, but as the largest vhich furnishes a private water supply for a part of the town is ›d in Newaygo County, this district is considered here.



ı.—Plat of Hesperia, Newaygo County, showing locations of wells and private waterworks.

HESPERIA.

. 14 shows the locations of the three wells. They are situated on ·ace adjoining White River and some 15 feet above the stream. ıpproximate elevation is 750 feet. The statistical data of the ıs wells are presented in the accompanying table for purpose of arison.

Wells of Hesperia district.

Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.[a]	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Galls.*	*° F.*		
Hotel	.....	750	.....	2	50	900	−20	.....	....	.....	
C. M. Perkins	.....	750	.....	2	100	850	0	.....	....	.....	
O. H. Johnson	R. Wilson et al.	750	Old.	2	180	770	T +34	Many.		Sand	Some iron.
H. K. Bush	J. F. Bush	750	1880	2	119	831	T + 5	8	48½	Gravel.	Sulphur, iron
D. M. Maze	.....	750	1888	2	118	832	T + 5	2	....	.....	Do.
John Carlisle	.....	750	.....	2	65	885	− 3	.....	....	.....	

[a] T = tested head.

The Johnson well encountered many seams of sand and gravel with water all the way down, as did the Bush and Maze wells, but, with the exception of a small supply in the Johnson well at 70 feet, no flows were obtained. The water at 180 feet in the Johnson well was found beneath 20 feet of clay, which stands without casing. In the Bush and Maze wells the upper part was predominatingly sand and the lower part predominatingly clay, with water in gravel at the bottom.

Mr. F. B. Henry, well driller, Wilcox Township, reports a 2-inc well, drilled for Robert Wilson, of Hesperia, in 1900. The depth 170 feet, the head is 38 feet above the surface, and the flow is ve strong. No such well was heard of when inquiry was made on t ground, unless it may be the Johnson well (formerly owned by G. Eldridge).

There are at least four different water horizons being drawn up in the town. The first general horizon is about 50 to 60 feet belo the surface, and, although not furnishing flows, it is the source most of the town wells, including the hotel and Carlisle wells. Th next horizon is that encountered by the Perkins well at 100 feet, an the water rises near enough to the surface to be piped laterally to trough on lower ground. The third horizon is at 120 feet and wa encountered in the Bush and Maze wells; it gives moderate flows The fourth is at 180 feet, yielding large flows and a strong head. very shallow horizon was also struck in 1899 by S. Hagerdorm at 1 feet, but the flow was poor and the well was abandoned.

The surface water is probably lowest in mineral matter, and as underlies a clay can be regarded as a safe drinking water. The wate from the 100-foot or 120-foot horizons carries little iron, but is marke by a large amount of sulphates, which is very unusual for Michiga drift waters. The 180-foot water shows no sulphates, but a consid erable amount of iron. Partial analyses are given in the table o page 91.

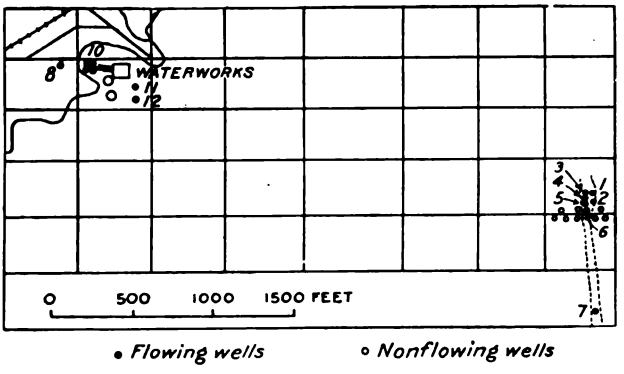
The wells are put to all ordinary uses—store, barn, hotel, an domestic. The Johnson well is especially important, since it afford

ıpply of a private water system, furnishing water to 15 buildings, ding a hotel, barber shop, market, and several private residences ig. 14). The water at the highest house will rise 8 feet above the ıd or 20 feet above the well. A large fountain in the yard of the r also gets its supply from the well.

seems almost certain that many more flows could be obtained both the 120-foot and 180-foot horizons by wells located almost here on the flat on which the town is situated. Flows may pos- be obtained on the high terrace at the southern edge of the town, they would be less satisfactory than on the lower land. An ınt sufficient for the town could probably be obtained from wells out much difficulty, and the sources are probably ample to supply ge number of private wells if not allowed to flow too freely. The ır appears to come from the morainal hills south of town.

FREMONT DISTRICT.

ı this district are included two clusters of wells in the town of nont itself, a group at Fremont Lake, a mile southwest of town, outlying wells in the SW. ¼ sec. 8, T. 12 N., R. 13 W., and in the sec. 22, T. 12 N., R. 14 W.



.—Plat of Fremont, Newaygo County, showing location of waterworks, mains, and important wells.

ıe location of the town wells is shown in fig. 15 and that of the out- wells in fig. 17 (p. 69).

FREMONT.

e town of Fremont has for many years obtained its water from the first being sunk about 1883. They were twenty in number, ɔeing 6 inches in diameter and the remainder 2 inches, and were ged along a trunk pipe extending west and a little north from the ɔing station, the four large wells being at the end of the pipe. ig. 15.) The depths varied from 60 to 97 feet, and the materials ıntered were gravel, sand (some of it much like clay), and a little

clay. Ninety-mesh screens were placed at the bottom, but soo became clogged, as the water carried much iron and lime. The ol wells failing to give an adequate supply, two new 2-inch wells wer sunk in 1902 to 225 and 226 feet, respectively, which together yiel 125,000 gallons daily. Much clay was encountered and some cemente material, like sandstone. The water is from immediately under a cla bed, and is strongly mineralized, carrying much iron, lime, and sul phates. (See table, p. 91, for partial analysis.) Some sand is brough up with the water.

The wells, which have a head of 20 feet, flow into two cisterns o reservoirs back of the station, from which the water is pumped int the mains. The ordinary pressure maintained is 60 pounds, but thi can be raised to 120 pounds if necessary in case of fire. There are 1 fire hydrants.

The wells at and near the Hagerdorm Laundry, in Fremont, ar located in a depression among low, rolling, drift hills, at an altitude c about 775 feet. The land rises distinctly both to the north and to th south.

The laundry is on the site of a former creamery. In digging a hol about 1901, in which to dispose of the refuse of the creamery flowin water was encountered, and this led to the sinking of six wells. (Fi 15, Nos. 1–6.) No. 6 is located in the laundry, and supplies the boile the others are situated in the rear of the building. No. 5 is the larges and is said to have thrown a jet 3 feet high from a 3-inch pipe the to of which is about 3 feet above the ground. The water flows into a so of reservoir. No. 2 feeds a small fish pond, and will throw a 2-inch je 1 foot high. The water was found underneath a rather uniform cla bed at approximately the same depths in all the wells, the differen depths depending upon the distance the pipe was driven into th underlying sand.

The water is free from iron and sulphates, and has only about ha the lime usually present in Michigan drift waters, which makes it a ideal supply for the purpose for which it is used. A partial analys will be found in the table on page 91.

The success of the laundry wells led the owners of adjoining propert to try for flows, but none were obtained, notwithstanding the fact th trials were made within 50 feet on both sides, one neighbor puttir down 6 test holes. The houses along the opposite side of the road a only about 50 feet apart, but, although all have wells deep enough have encountered flows, none were obtained. A block and a ha south, however, Mullins & Bode obtained a flow from the same horiz as the laundry, as was determined by the fact that its supply was c off in three hours when the largest laundry well was allowed to flo freely (No. 5). This would indicate that the water seam continues f some distance, but that it is very narrow. The width can not be mu

50 feet, as it was not encountered by the neighboring houses. Its ı suggests an old sand-filled stream channel afterwards covered by . The source of the water is probably the low hills to the south. re is some talk of utilizing the wells for a fish hatchery or public :.

he character of the materials in the adjacent wells is very variable. ıe find sands with nonflowing water, others all clay, still others in part and sand, with water rising nearly to the surface. One a block north went 200 feet without getting water at all. There ıs to be some clay in the water-bearing bed at the laundry, as the ɜr was roily during thunderstorms when the wells were first sunk. flow is said to slacken when the wind is northwest.

he largest well in Fremont outside of those already mentioned is tannery well, which is variously reported as from 200 to 280 feet). What appears to be the best information places it at 225 feet, ıe same as the adjacent waterworks well. A shallow well, 18 feet), which will flow at 1 foot above the surface, is reported at the ɜe of John Timmer, but a pump is used to raise the water to the . Mr. Yergin, at the west end of town, is said to have a small , while still another has been reported at the planing mill beyond railroad.

FREMONT LAKE.

he wells at Fremont Lake are located on a low, flat, sandy terrace a feet above the water's edge and within a few hundred feet of the e. A short distance farther back the land rises abruptly some 20 or more to a rolling terrace, while still farther north it becomes r. The materials penetrated in the different wells are quite vari- :. In the Chamberlain well they were as follows: Sand 95 feet, 30 feet, sand 18 feet (water at 54 feet and at bottom), while in Hain well there was sand to 50 feet, then clay to 100 feet. A well

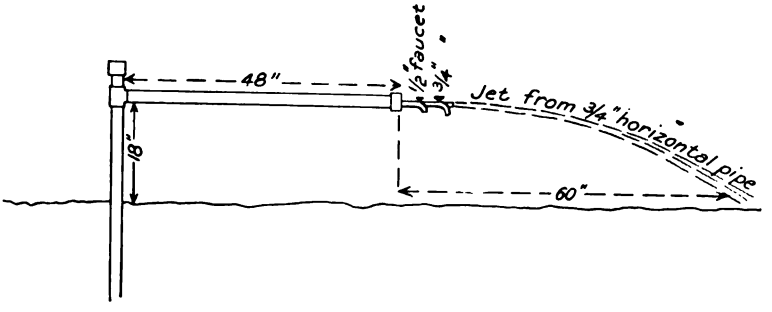


FIG. 16.—Arrangements at Hain well, Fremont Lake, Newaygo County.

k by Gerber, Raider, Schoolmaster, and others went 300 feet ɔugh alternating clay and sand. It is said some water was ained at 150 feet and at the bottom, but the pipes clogged and the

supply was lost. It is reported that it was intended to dynamite th well at 100 feet, but by accident the charge went off at 50 feet an spoiled the well. No flows were reported. Further data relating t the wells are given in the table on page 70.

The Hain well is so piped that it is possible to determine the flow un der a number of different conditions. The results are presented below The well is 2 inches in diameter, the casing projecting about 2 fee above the surface. At 1½ feet a 2-inch horizontal pipe 4 feet in lengt is attached, at the end of which is a ¾-inch pipe with two faucets, ½ and ¾-inch, respectively. (See fig. 16.) The results of the measure ments were as follows:

Measurements of flow of Hain well.

	Gallons per minute.
Both faucets flowing:	
¾-inch faucet	[illegible]
½-inch faucet	[illegible]
Combined flow	[illegible]
One faucet flowing:	
¾-inch faucet	[illegible]
½-inch faucet	[illegible]
Faucets removed:	
¾-inch horizontal pipe	[illegible]
Estimated yield if flowing from 2-inch horizontal pipe	[a] [illegible]

OUTLYING WELLS.

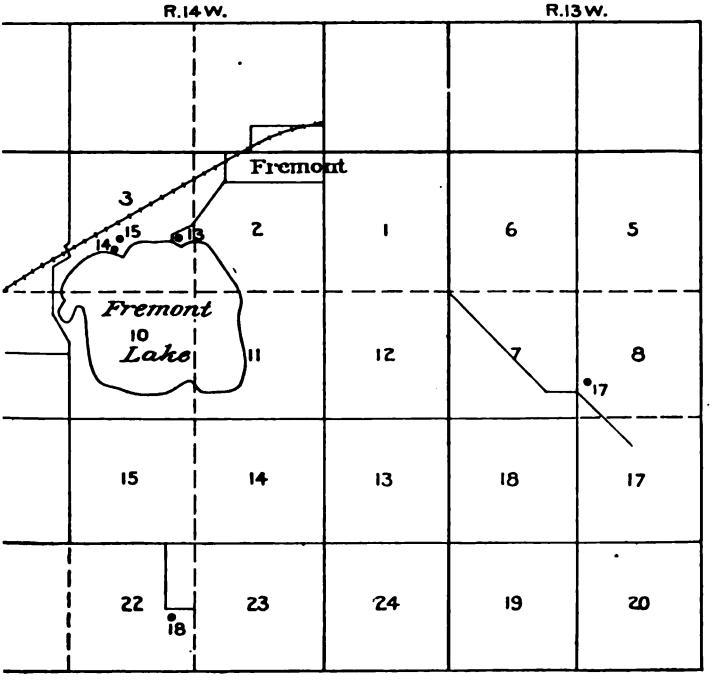
The schoolhouse well (fig. 17) is located in sec. 8, T. 12 N., R. 13 W. on a southwest-facing slope, about 10 feet below the crest of a ris immediately behind it and about 10 feet above the creek bottom ir front. South of the creek, in the SE. ¼ sec. 7, are low, rolling, drift hills. All other wells in the vicinity are shallow. The water pre sumably comes from the north, probably for some distance, as th hills in the immediate vicinity are thought to be too low to give th observed head. The water tastes of iron. A partial analysis is give in the table on page 91. For additional data see table on page 70.

The H. B. Markle well (fig. 17) is located in sec. 22, T. 12 N., R. 14 W on the north slope of the morainic hills in the S. ½ sec. 22, about 1 feet above the west-east valley extending across the center of th section. The water probably comes from the south. The flow h decreased considerably on account of clogging. The water is high i iron and carries about the usual amount of lime. The table on pa 70 gives additional data.

[a] Dependent on the quantity drawn upon and the ability of the sand to give up its supply with su cient rapidity.

SUMMARY.

nber of flowing wells at Fremont is greater than in the major-
tricts, largely because a greater number of deep wells have
: on account of lack of satisfactory shallow supplies such as
only present in Michigan. There is no single horizon of any
ent, each well or group of wells drawing from an independent
n of very limited extent. At the laundry, as has been
, the water-bearing bed is less than 50 feet wide, and even at



IG. 17.—Map showing relation of outlying flowing wells of Fremont district.

where the conditions for flow are most favorable, one 300-
failed to get water. Near the schoolhouse well flows may
be had along the creek valley or a few feet above, but they
bly be small. Somewhat larger flows might be found in the
ar the Markle well. The points most favorable for flows are
adjacent to hills of considerable elevations. Flows would
be quite general about the shores of Fremont Lake.

The statistical data of all the wells are given in the table below:

Wells of Fremont district.

No. on figs. 15 and 17.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Maximum head.	Flow per minute.	Temperature.	Water bed.	Quality water
			Ft.		*In.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	F.°		
1	S. Hagerdorm.	S. Hagerdorm.	775	1901	2	20	(a)	+2	+ 8	Cap.	48½	Sand	Very soft
2	do	do	775	1901	2	15	(a)	+2	+ 8	M.	48½	Coarse gravel	Do.
3	do	do	775	1901	2	20	(a)	+2	+ 8	Cap.	48½	Sand	Do.
4	do	do	775	1901	2	20	(a)	+5	+ 8	1	48½		Do.
5	do	do	775	1901	3	18	(a)	+2	+ 8	M.	48½	Pocket	Do.
6	do	do	775	1901	2	29	(a)	+2	+ 8	M.	48½		Do.
7	Mullins & Bode.	Heinde	780	1903	2	23	757	+ ½	+ 2	4	48½		
8	Tannery		780		2	224	556		+20	M.			Hard.
10	City waterworks.	Company and J. A. Heinde.	780	1883	6, 2	60–100		+0	+20	Med.		Sand	Iron.
11	do	do	780	1902	2	226	554	+0	+20	M.		do	Hard.
12	do	do	780	1902	2	225	555	+0	+20	M.		do	Do.
13	Jas. Odell		770	1899	2	108	662		+16	36	48½	Sand, gravel.	Iron.
14	G. E. Hain		770	1904	2	101	669	+2	+12	40	48½	Coarse sand.	Do.
15	N. L. Chamberlain.	Biglow	772	1901	2	138	634	+2½	+14	8	48½		Slight iron.
16	D. Gerber et al.		770	1903	2	300		−0					
17	School		710		2	70	640	+1		1	48½		Do.
18	H. B. Markle.		720	1890	2	200	520	+6		2	48½		Hard.
19	John Timmer.[b]			1901		18		+1					Soft.

[a] Bottom of clay at 760; wells go different depths into the water-bearing sand.
[b] This well has cistern pump attached with spout high enough to prevent a flow.

NEWAYGO.

FLOWING WELLS.

The Newaygo district, which has about 10 wells, is located al the State road, the principal street in town. The wells (fig. 18) all sunk to an imperl terrace 15 to 30 f above the flood plai Muskegon River. B of the lower terrace land rises abruptly the extensive upper race 100 feet or n above the river. wells are within a hundred feet of the l of the bluff. The ca ment area is probably on the upper terrace, perhaps several n back from the river.

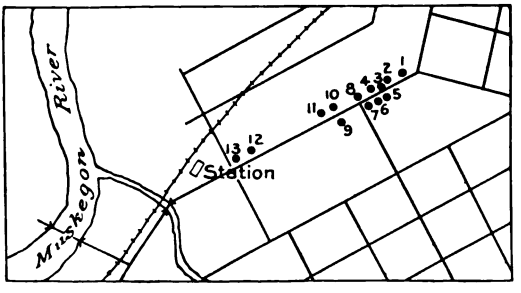


FIG. 18.—Plat of Newaygo, showing location of waterworks, mains, and flowing wells.

Much of the information relating to the wells is given in the t

low. From this it appears, after making allowance for slight variations in the level of the ground and in the depths of the wells, that all the wells, with the exception of the Eckard and Whitman wells at the east end of town, obtain their supplies from a single shallow horizon 30 feet from the surface. The first flowing well was obtained about thirty years ago by Edwards (at hardware store). This was dug 20 feet and then bored with auger to a water bed at about 30 feet, at which depth a powerful stream, which filled the well and overflowed to the surface, was encountered. The well has since clogged up and is now pumped. In fact, all the wells show more or less loss of water from clogging, supposedly by clay, but possibly from the deposition of mineral matter on the screen. The materials encountered are alternating sands and clays, largely the latter, the water being generally found in gravel beneath the clay.

For description of the flowing wells at the waterworks see discussion of the public supply (p. 72).

Wells of Newaygo artesian district.

No.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Maximum head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Ft.*	*Gal*	*F.*		
1	S. K. Riblet [a]	Unknown.	690		2	30	660	−0	− 0				
2	J. F. A. Raider [b]	Raider	690	1885	2	35	655	+2	+ 8			Gravel	Iron; medium.
3	Thompson Bros. & Co. [c]	Teachout	695	1884	2	32	663	+1½	+ 6	¼	48	Sand	Iron sulphate; medium.
4	do. [c]	Unknown.	695	1889	2	30	665	+1½	+ 6	¾	48		Iron; medium.
5	Odd Fellows block. [d]	do	695	1885	2	35	660	Pumped.	+12			Gravel	Do.
6	R. Surplice [e]	do	695	1883	3	40	655	Pumped.	+12			do	Do.
8	Gleason's drug store. [f]	do	695		2	30	665	+0					Do.
9	J. W. Brown [g]	Owner	695	1883	2	30	665	+1		1			Do.
10	Mrs. McGraw [h]	Unknown.	690		2	30	660	−0	+ 0				Do.
11	J. F. A. Raider [i]	do	690		2	30	660	+2½		7	48		Slight iron; medium.
12	Louis Eckard [j]	do	670		2	50	620	−1½				Gravel	Iron; medium.
13	Wm. Whitman [k]	do	665	1885	2	49	616	±0		2			Do.

[a] Only known failure within limits of developed area; failure probably due to fineness of water-bearing material.
[b] In a cellar about 7 feet below sidewalk. Strong flow at first utilized in a fountain in the store, but as it prevented the flow of adjacent wells it was stopped down.
[c] Decreased in flow. Nos. 3 and 4 are only 50 feet apart, and when No. 4 at corner of the building outside sidewalk is allowed to flow freely No. 3 at the watering trough ceases or is greatly diminished.
[d] Does not flow now, but is drawn to the second story by a suction pump.
[e] First successful flow.
[f] In sidewalk in front of the store; now capped.
[g] Sulphur water, piped 250 feet to the next house west. Although the piping leaked badly when seen, there seemed to be considerable pressure and a good flow.
[h] Ceased to flow; remedied by forcing small pebbles through pipe into clay at bottom.
[i] In lot next west of Methodist Church.
[j] Roily water.
[k] Flowed for eight or ten years, but has now ceased.

The quality of the water is indicated in the table. It is medium hard and carries somewhat more than the average amount of iron. A partial analysis of the Thompson well (No. 4) is given on page 91.

The prospects for extending the district drawing from the present horizon are slight. If more wells were sunk, they would doubtless obtain flows, but would result in a loss to the other wells, since the supply is nearly all used. Surface supplies are to be had in abundance; in fact springs of some size formerly broke out where the road now is, but they would be dangerous to use for drinking purposes. It is stated that the flowing wells in town are affected by the drawing of supplies from the waterworks wells. If this is the case, it would point to a common water bed. It is not improbable that other flows could be obtained by going deeper, say from 50 to 150 or 200 feet. This may soon be desirable if the town continues to draw a portion of its supply from the creek.

WATERWORKS.

The water system of this place is owned by the town and has the reputation of being one of the cheapest in the State. The waterworks are located in a deep ravine cut by a creek crossing the terrace above the town. This terrace is about 70 feet above the village, but the waterworks are perhaps 60 feet lower. The supply is from about 14 wells, most of them 2 inches in diameter and 18 to 20 feet deep. Six are located in the large cistern in the rear of the plant and eight are outside. All but two flow, the water rising about 4 or 5 feet above the surface and being conducted into the cistern, which is 14 feet deep and 22 feet in diameter. The cistern fills to within about 2 feet of the top and would probably overflow if the supply was not drawn upon. The tops of the wells are about 6 feet below the top of the cistern.

The supply from the wells is about 500,000 gallons per twenty-four hours and was ample until recently, when the large cement plant began using water. It is now necessary to draw from the pond just above the pump house. The water carries some iron and is fairly hard, but is used in boilers.

The water is forced into the mains by means of pumps operated by water power, the pressure required to force it over the hills in volume sufficient for the demands being about 45 pounds. The pressure in town is 60 pounds. The location of the mains is shown in fig. 1[illegible] There are about 15 fire hydrants.

The use of the water from the stream or pond should be discouraged, as it is practically impossible to foresee or prevent pollution even with the present small number of buildings on the watershed. The health of the users of the supply should not be endangered for the sake of the additional revenue derived from the sale of water to the cement plant or other manufacturing establishments. A safer way than drawing from the river would be to sink more wells or, perhaps, utilize the large springs near the station. The water, however would be hard and would carry some iron.

ENSLEY DISTRICT.[a]

Ensley flowing-well area is about 12 square miles in extent, and ıt east of Rice Lake in the two eastern tiers of sections of Ensley hip. There are eight flows in all, yielding a total supply of 41 gallons a minute (fig. 19). The development of this area is ınt date, the first well being driven in

The water contains a considerable ıt of iron, which incrusts the pipes. raphically the area is of strong relief central part, and is thus suitable for

It lies on the western border of a andy moraine, which is probably the nent area for the artesian supply. Its ırn part is flat, with a clayey subsoil. hole is drained by small westward- g streams, which empty into Rice Lake ɔutlet, River Rouge.

following record of material illustrates ındy portion of the district, but in clay is at the surface.

Record of Albert Marvin well.

	Thickness.	Total.
	Feet.	*Feet.*
yellow sand, water-bearing	30	30
drysand	15	45
ıy with stones	15	60
l, growing coarser with increas- ɔth until coarse water-bearing s encountered	21	81

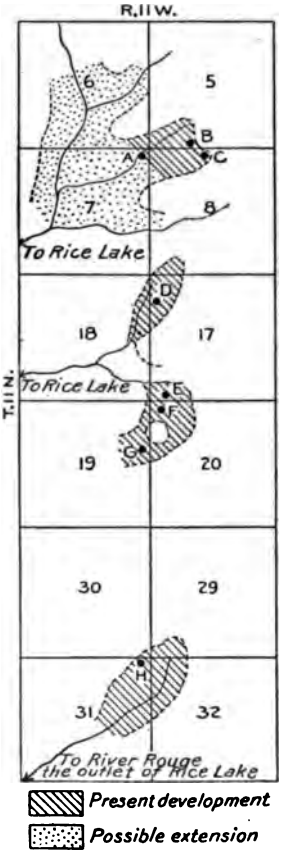


FIG. 19.—Location of Ensley flowing wells, Newaygo County, in relation to local drainage.

above well is exceptional in the area ıe its flow has decreased. This is as- by the owner to the corrosion of the ınd the incrustation of the screen. a small flow and water containing a ɔercentage of iron this occurs more y than with a strong flow. It is a condition, nevertheless, l which all the wells furnishing chalybeate water are tending. re is opportunity for much further development of the area, and empt to get a flow on the western and southwestern borders of ea has been unsuccessful so far as known. The ability to get a 'ul supply at a depth of a few feet often delays the complete pment of an area, despite the fact that in the case of a flow at an 200 feet there is a good return for the outlay.

[a] Data by Isaiah Bowman.

Wells in Ensley district (T. 11 N., R. 11 W.).

Letter on fig. 19.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
A	7	School district No. 3	.....	113½	833?	849?	20	[illegible]
B	5	James Downing	1901	45	883	883	.....	.....
C	8	J. Hanson	1894	45	880	883	.33	51
D	17	J. Hunsinger	1901	30	883	889	.5	50
F	20	J. M. Small	1895	657	884	886	.5	50.5
E	17	David Hotell	1900	54	888	900+	18	50.1
G	19	A. Marvin	1899	81	880	882	.75	[illegible]
H	31	School district No. 9	.....	112	888	891	1	[illegible]

ISOLATED FLOWS.

In addition to the foregoing districts, a number of isolated flowing wells have been reported. These are given below:

Kirk.—A flow rising several feet above the surface is reported, but details are lacking.

Volney.—A well sunk by S. Hagerdorm on a ridge in village of Volney found water, which rose to surface at 40 feet. If located a few feet to one side, wells would flow. The conditions are not uniform, however, as another well near by went 80 feet in sand and gravel without getting a flow.

Lincoln Township.—A well with a small flow is reported on property of C. Kent, about 4 miles northwest of Whitecloud.

Wooster.—A well flowing a ½-inch stream is reported on the Murphy and Hill farm near Long Lake, Wooster station, Sherman Township, a few miles northeast of Fremont.

Brunswick.—A well is reported to have been drilled by S. Hagerdorm in NW. ¼ sec. 18, T. 12 N., R. 14 W., in 1902. It is located in a flat district, with elevation about the same as the railroad (approximately 750 feet). The depth is 28 feet and diameter 1¼ inches. The material is all clay down to water-bearing gravel. The well flows a ¼-inch stream of hard water, with much iron, giving considerable scale.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Newaygo County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Springs.
		From—	To—	Common.		
		Feet.	*Feet.*	*Feet.*	*Feet.*	
Etna	No returns					
Ashland	Driven wells	20	45	35	35	Small.
Big Prairie	Driven and open wells	12	160	75	50	Medium.
Bitely	Driven wells, springs	8	16	12	16	Large.
Bridgeton	No returns					
Brunswick	do					
Croton	Driven wells open wells, river	12	40	20	18	
Diamondlock	Driven wells, springs, lake	20	120	80	80	Small.
Fremont	Driven wells (some flows)	15	250		250	Do.
Goodwell	No returns					
Grant	Driven wells	15	35	25	30	Do.
Hawkins	Driven wells, creeks, lakes	8	70	25		Do.
Huber	No returns					
Hungerford	Driven wells, creeks	20	150			Do.
Newell	Driven wells, springs, creeks	8	12	12	12	Variable.
Kirk	Driven wells and open wells, creeks	12	60	40	40	Large.
Lake	Driven wells, creeks	12	32		30	
Lilley	No returns					
McLeans	Driven wells	10	25		25	Do.
Newaygo	Driven wells, river, and creek	20	130			Variable.
Otis	Springs and lake	14	75	35	70	Large.
Parks	Driven and open wells, creeks	16	100	30	30	Do.
Reeman	Driven wells	16	80			Small.
Shaw	do	20	105	35	35	Large.
Volney	Driven wells, creeks	8	25			Small.
Whitecloud	Driven wells, river			25	25	Do.
Woodville	Driven wells	15	25			
Wooster	do	50	70	65		Variable.

WATER SUPPLIES OF MECOSTA COUNTY.

By Myron L. Fuller.

TOPOGRAPHY.

Mecosta County, of which Big Rapids is the county seat, is situated a little west of the center of the Southern Peninsula. It was covered by the Saginaw Glacial lobe, its western part being in an interlobate moraine between the Saginaw and Lake Michigan lobes. This moraine and others closely associated with it cover the western half of the county. East of the morainic system is a gravel plain several miles wide, while on the eastern border of the county is another morainic system. Muskegon River traverses the interlobate moraine in the western part of the county in a deep valley a mile or more in width. The gravel plain referred to above is drained southwestward by the Little Muskegon, except in the northeastern part of the county, which is tributary to Chippewa River, which flows eastward. The same gravel plain thus contributes water both to Lake Michigan and to Saginaw Bay.

In the morainic belt many deep wells have been made, in which water stands far below the surface, flowing wells being obtained only on the low ground along the streams. In the gravel plain and in the

valley of Muskegon River an abundance of water is found at moderate depths, but a few deep wells have been sunk at Big Rapids and Mecosta to get supplies below the surface water.

FLOWING WELLS.

BARRYTON DISTRICT.

The flowing-well district at the growing town of Barryton, in the northeastern township of Mecosta County, is the largest in the county. The flowing wells, five in number, are scattered over a large part of sec. 27, T. 16 N., R. 7 W., one being just across the road from the northeast corner of sec. 22. The developed area is something over one-half square mile, but it would doubtless be greatly extended if more wells were sunk.

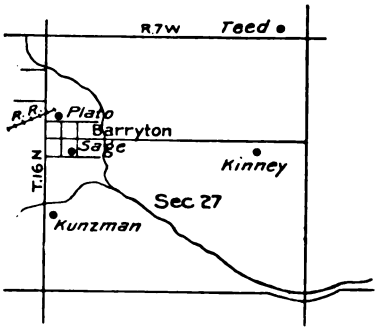


FIG. 20.—Sketch map of Barryton artesian district, Mecosta County.

The town and wells, except the Kunzman well, are located on the flood plain or terrace of Chippewa River, about 10 feet above the stream. On the south side of the river the land rises sharply into morainal hills, which also extend around to the west and north and west of the town, but at a greater distance from it.

For purposes of comparison the data relating to the wells have been grouped, as far as possible, into the tables given below. The location of the wells is shown in fig. 20.

Wells of Barryton district.

Owner.	Driller.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.[a]	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Galls.*	°*F.*		
Plato, Renwick & Co.	Sam Shores	970	1894	2	139	840	T 9	Small.	....	.....	
Sage	.....	970	1898	2	70?	900	F 10	1	....	.....	
E. Kunzman	Moyce Bros.	970	1903	2	60	910	T 8+	4	48	Sand	Slight iron.
W. D. Teed	.....	980	1894	2	97	883	F 3	Small.	....	.....	
John Kinney	Moyce Bros.	975	1903	2	72	903	T 9	5	48	Gravel	Hard.
H. Walroth	.....	975	.....	2	120	(?)	.....	.....	....	.....	

[a] T = tested; F = flows.

It is significant that the three wells of which records could be obtained, the Kinney, Teed, and Kunzman, all passed through essentially similar materials, consisting of a few feet of sand at top, then clay down to the thin water sand at bottom. The Sage well also draws from the same horizon, but the Plato-Renwick well comes from

bed about 55 feet lower. It is said that the Teed well is affected by the wells in town, and it is certain that its head, which was formerly 3 feet above the surface, has now been so reduced that the water only barely reaches the surface and has to be pumped.

The slope of the upper sand is clearly shown by the wells, its altitude being 910 feet in the Kunzman well, 900 in the Sage and Kinney wells, and 883 in the Teed well. Notwithstanding the good flows which it gives when the wells are properly sunk, it was drilled through in two instances—the Plato-Renwick and Sage wells—to the inferior sand below. The former, which still flows, draws from the lower sand, but the pipe in the latter was pulled up to the upper sand. The Sage well is now partly clogged, and the flow and head much reduced. It originally flowed as high as the second story of the house.

The water is about the same as the average drift water of the State, being fairly hard and containing some iron. A partial analysis of the water from the Kunzman well is given in the table on page 91. The water is used for store, domestic, and farm purposes, is perfectly safe for drinking, and is much preferable to the waters of the shallow wells, which are in general use in the town.

The source of the water is in the morainal hills south of town, as is indicated by the slope of the beds from that direction. It is almost certain that flows can be obtained almost anywhere in sec. 27 when the elevation is not more than 15 feet above the river. Flows could also probably be obtained on the flats at similar elevations with reference to the river, both above and below town. It is thought a supply sufficient to meet the demands of the town could be had by drilling a series of wells along an east-west line parallel to the creek on the west side of town.

The available supply of the water sand seems to be large, but if a considerable number of wells are drilled it would be wise to stop down the flow to a point where it just meets the need and not allow the water to run to waste.

SHERIDAN TOWNSHIP.

The school well of the first district is located at the crossroads on a hillside in the southwest corner of sec. 1, T. 15 N., R. 7 W., about 15 feet above the bottom of the valley. Its elevation is about 965 feet, but a short distance to the north the morainal hills rise considerably higher. The well, which is the property of the school district, was drilled in 1901 by Moyce Brothers. It is 2 inches in diameter, 59 feet deep, and flows 20 gallons a minute from a 1-inch discharge pipe. A much stronger flow was obtained from the original 2-inch casing. The water will rise 24 feet above the surface. It now issues into a circular cement tank 5 feet in diameter, protected by a *spring house*, an overflow pipe leading to a trough by

the roadside. The water tastes strongly of iron, has a slight c of sulphur, and is decidedly hard. A partial analysis is give the table on page 91. Its temperature is 47½° F. Clay was countered most of the way down to water gravel.

Other wells among the hills within a distance of a mile have g for 100 to 180 feet without finding flows. There appears to b general water-bearing horizon, and flows will be difficult to obt although they might be had by wells in the near vicinity of schoolhouse well, and possibly elsewhere.

MECOSTA.

The village of Mecosta has a small flowing well at the wate trough on the main street near the eastern edge of town. located on a flat slightly above the adjacent valley on the wes an elevation of about 950 feet. It was drilled by R. D. Park 2 inches in diameter, 160 feet deep, and flows about one-half g a minute at 1 foot above the surface, although it is said that it rise 2 feet higher. The flow has decreased considerably, owin clogging of pipe. The temperature is 49°, and the water t slightly of iron. (See partial analysis in table, p. 91.) The m rials penetrated were: Wet sand, 110 feet; clay, 45 feet (with w at 140 feet); sand, 5 feet. Probably other flows could be obta on the flat on which the village is located, especially near the of the surrounding hills. The elevation of these hills in the in diate vicinity, however, is not high, and large flows or strong h are not to be looked for.

PARIS.

A flowing well is located at the fish hatchery about 10 feet b the Paris station, which has an altitude of 928 feet. It is 2 in in diameter, 135 feet deep, and flows 8 gallons a minute. It drilled in 1902 by J. K. P. Snyder & Son, and its head tested height of 7 feet above the surface. The materials penetrated mainly sand and gravel, with about 15 feet of clay below 100 The water tastes of iron and rapidly corrodes the pipes.

MILLBROOK.

It is reported that Philip Capen has a flowing well at Millbr in the southeastern part of the county, but it was not visited no data concerning it were obtained.

TOWN SUPPLIES.

BIG RAPIDS.

About 1892 an attempt was made in Big Rapids by Mr. C Waring to develop a water supply from wells, his intention bei dispose of it to the city if successful. It is said that nearly a

dred 2-inch wells were sunk. No flows were obtained, and because of the failure to pump successfully the project was abandoned. It is said that a similar difficulty was encountered at Jackson, but was finally overcome by the use of the air-lift process.

At present the supply is taken directly from the Muskegon River without filtration. There is generally more or less typhoid fever, and a few years ago a severe epidemic occurred. Although this was attributed to the use of open wells, and was possibly independent of any pollution of the river water, it is certain that as long as the river is used an outbreak is liable to occur at any time. The pollution from a single case of typhoid at a point within a distance of several miles upstream might lead to hundreds of cases in town. The river and shallow wells should be abandoned as a source of domestic supply. Deep wells located possibly along the river above town would afford the most desirable source.

In the present system direct pressure is used, but the erection of a standpipe is contemplated. The domestic pressure is 65 pounds at the pumping station, and the fire pressure is 110 pounds. The pressure in the town is 27 pounds less. The daily capacity of the two pumps is 1,300,000 and 500,000 gallons, respectively. There are 11 miles of pipe from 4 to 18 inches in diameter and 9 fire hydrants. The plant is owned by the city.

MISCELLANEOUS.

Village supplies in Mecosta County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Altona	Driven wells, river	20	25	25	25	.....	Small.
Barryton	Driven wells, artesian wells	.....	.....	.....	.....	.....	Medium.
Big Rapids	River driven wells	18	90	40	.....	.....	Small.
Borland	Driven wells	20	60	40	40	−25	Do.
Chippewa Lake	Cisterns, wells, lakes	14	90	90	90	.....	Large.
Emerald	Driven wells, lakes	50	160	140	.....	.....	Do.
Mecosta	Driven wells, artesian wells	16	190	.....	165	± 0	None.
Millbrook	do	9	90	30	.....	+ 2	Large.
Morley	Driven wells	20	40	30	30	−20	Small.
Paris	Driven wells, artesian wells	.....	.....	.....	.....	± 0	
Pogy	Driven wells	80	152	125	125	.....	Do.
Remus	do	12	120	50	.....	.....	Do.
Rodney	do	50	60	55	60	.....	None
Sandy	Driven wells, dug wells	.....	.....	.....	.....	.....	
Stanwood	Driven wells	15	20	.....	.....	.....	
Stimson	Driven wells, springs	20	120	.....	.....	.....	Small
Titus	Driven wells	15	80	25	.....	.....	Large.
Weaver	do	24	90	50	40	.....	Small.

WATER SUPPLIES OF MASON COUNTY.

By Myron L. Fuller.

GENERAL STATEMENT.[a]

Mason County borders on Lake Michigan near the middle of the eastern side of the lake, Ludington being the county seat. It lies immediately north of Oceana County, and one of its flowing-well districts extends into that county. The southern half of the county is drained mainly by Pere Marquette River, the northern part by Great Sable River, and the intervening territory by Lincoln River. The streams all have wide mouths or lakes lying back of a range of dunes that border the shore of Lake Michigan. There is a belt of sandy country from Ludington northward along the shore of Lake Michigan, which is unsettled, the settlements beginning 4 to 6 miles back from the lake. The northern part of the county also is a sandy plain, with very few settlers north of Great Sable River. Along the south side of this river, from near Freesoil westward for about 10 miles, is a morainic belt, which is settled and has numerous wells 50 to 100 feet in depth. South of this is a sandy strip along Lincoln River, which is sparsely settled. There are few settlers in the eastern range of townships except in the vicinity of Branch, Bachelor, Tallman, and Millerton. As is indicated in the tabulated data below, the wells at these villages are generally shallow. The central and southwestern parts of the county are pretty well inhabited. Water is usually obtained at moderate depths except on the high range of hills fronting Lake Michigan south of Ludington, where some wells are 100 to 150 feet in depth. A few flowing wells have been obtained along the Pere Marquette Valley near Ludington and Amber, and there is a small district in the southwestern part of the county bordering Bass Lake.

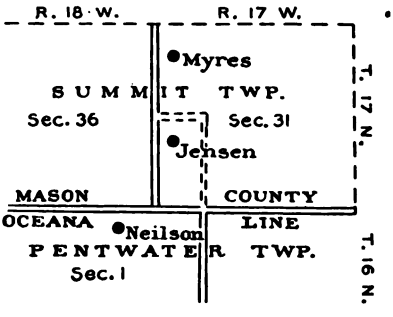


Fig. 21.—Sketch of Bass Lake artesian district, Mason County.

FLOWING WELLS.

BASS LAKE DISTRICT.

This district lies east and south of Bass Lake near the line of Mason and Oceana counties, two wells being in sec. 31, T. 17, R. 17 W., Mason County, and a third in sec. 6, T. 16, R. 17, Oceana County. The district is limited on the east by a till ridge capped by sand, but it may be

[a] By Frank Leverett.

ctended westward and southward. It can not well be extended orthward, as the country rises rapidly in that direction.

The locations of the wells are shown in fig. 21, and the data relating o them have been compiled in the following table:

Wells of Bass Lake district.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.[a]	Flow per minute.	Temperature.	Quality.	Water bed.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
harles Myres.....	1901	2	102	600	T.+15	4	50.5	Hard; iron	Gravel.
. Neilson.....	1901	2	85	585	T.+10	2	49.75	.....do.....	Sand.
. C. Jensen.....	1892	2	122	590	F.+ 2	2	.....	.....do.....	Gravel.

[a] T.=tested; F.=flows.

The Myres well penetrated gravel and sand 10 feet, clay 90 feet, and ravel 2 feet. In the Jensen well the clay was 83 feet thick. In the Neilson well much trouble was experienced in driving the pipe, and as t was finally broken it seems probable that clay was encountered, as n the other wells. The Myres well alone discharges in the ordinary vay above the surface; the Jensen well is connected with a pump, which raises the water into the house, while the Neilson well opens into plank-lined cistern, from which it overflows. No material decrease n flow has been noted except in the Neilson well, for which the broken asing is probably responsible, as some of the water now rises along he outside of the pipe.

There may be another flowing well on the Anderson farm, a mile outh of the Neilson well, for near the house a pipe was found which verflows into a tank in the barnyard. This pipe is in a box inserted n the ground, from which a horizontal pipe leads toward the house, robably to a pump. No other data were obtainable.

The water of this district tastes quite strongly of iron and is harder han the average Michigan water. It is, however, used for all domesic and farm purposes. A partial analysis is given in the table on age 91.

The source of the water is probably in the bordering sand-covered lay ridge a short distance east of the wells, though it may be at a reater distance.

WATERWORKS.

Waterworks have been installed at Ludington and at Scottville. The Ludington supply is drawn from Lake Michigan. Though originally built by a private company, the system is now owned and operated by the city. The Scottville supply is from a well 54 feet deep, from which water is pumped to an elevated tank. The village owns the plant, which was installed in 1898.

MISCELLANEOUS VILLAGE SUPPLIES.

The following date concerning village supplies were obtained by correspondence with residents of the villages:

Village supplies Mason County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amber	Driven wells (some flow)	10	.....	40	150	±0	Small.
Bachelor	Driven well	15	20	.....	.....	.....	
Branch	No returns	.....	.....	.....	.....	.....	
Buttersville	Driven wells, lake	25	500	.....	500	±0	
Carrs	Driven wells, creek	15	98	30	30	.....	
Custer	Driven wells, open wells	15	96	45	45	.....	Large.
Fern	Driven wells	16	62	50	62	.....	Small.
Fountain	Driven wells, river	14	94	40	97	.....	Do.
Freesoil	No returns	.....	.....	.....	.....	.....	
Ludington	Lake, wells (salt wells)[a]	6	2,000+	20	10	.....	Do.
Manistee Junction.	No returns	.....	.....	.....	.....	.....	
Millerton	Driven wells and creek	22	28	26	26	.....	Do.
Scottville	Driven wells	25	77	45	50	.....	Do.
Tallman	Driven wells, lake	20	35	30	30	.....	Variable.
Weimer	No returns	.....	.....	.....	.....	.....	

[a] The Ludington salt wells are nearly 2,000 feet deep, and are reported on in volume 5 of the Michigan Geological Survey. They penetrate about 600 feet of drift, mainly sand, which is a good water bearer. The rock surface here is about at sea level. No other borings in the county have reached rock, so it is not known whether it has a low altitude far back from the shore of Lake Michigan.

WATER SUPPLIES OF LAKE COUNTY.

By Frank Leverett.

Lake County is situated west of Osceola County, in the western part of the Southern Peninsula, Baldwin being the county seat. Its eastern range of townships are in the elevated interlobate moraine between the Saginaw and Lake Michigan lobes, the greater part of which lies in Osceola County. The highest points in Lake County are about 1,300 feet above sea level. The remainder of the county is largely a gravel plain; but the southwest township has morainic belts, and there are several small moraines in the northwestern quarter of the county. The settlements are mainly in the eastern part of the county on the interlobate moraine, the county seat being the only village west of the moraine. The gravel plain is dotted with lakes in the vicinity of Baldwin and southwestward to the edge of the county, and the water table in this part of the gravel plain is usually within 40 feet of the surface. There are also lakes in the northwestern part of the county, on the borders of which water is reached at convenient depths; but as a rule the gravel plains are so high above the lakes and streams that the water table lies at depths of 50 to 100 feet or more. The settlements in the eastern part of the county are mainly on the lower portions of the morainic belts, the high points being usually rather barren, gravelly, or sandy knolls. Wells have been obtained

ese depressions at depths of 50 feet or less. At the Carr settle- ; in the southwestern part of the county, which is partly on a ıine and partly on a till plain west of it, wells range in depth from › 100 feet or more. The drift in this county is probably several lred feet in depth, but as yet no borings have reached the rock. ıe following data on village supplies have been obtained by corre- dence with the residents of the respective villages:

Village supplies of Lake County.

vn.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
·ine..	388	834	Driven wells.....	12	16	12	12	−10	Large.
ld...	.....	868	.....do.....	18	27	20	20	−18	None.
.....	300±	1,075	.....do.....	25	65	25	60	−10	Small.
ın...	.....	856	.....do.....	16	30	20	20	−16	Large.
rb...	837	975	.....do.....	20	30	25	25	−24	Do.
na...	.....	975	.....do.....	8	25	20	20	−8	Do.

: Pere Marquette Railroad furnishes a partial water supply and is to put in fire hydrants. The is pumped from a well at the station to an elevated tank.
: village has six cisterns averaging 200 barrels each, which are used for fire protection.

WATER SUPPLIES OF OSCEOLA COUNTY.

By Myron L. Fuller.

GENERAL STATEMENT.[a]

ɜceola County has the distinction of containing the highest point ıe Southern Peninsula. It is about 1,700 feet above tide and is ;ed on the northern edge of the county in sec. 12, Sherman Town- . The interlobate moraine between the Lake Michigan and naw Bay lobes occupies the western half of the county, and its ıills extend eastward nearly to the eastern limits of the county, e being little or no flat surface, except in the valley of Muskegon ·r and in the swamps inclosed among the morainic knolls and ·s. The elevation of much of the interlobate moraine is above 0 feet, and that of Muskegon River is about 1,000 feet where it rs the moraine near Evart. The Lake Michigan lobe extended into the western range of townships and into the edge of the 'e east, the remainder of the county being within the limits of the naw lobe. The county is all tributary to the Muskegon, except ıorthwest corner, which drains to Manistee River, and the south- corner, which drains to Chippewa River.

uch of the elevated morainic country is very sparsely settled, so few borings for water have been made. The very high tract in northern end of the county, however, is settled and has some deep s. One on the farm of Albert Miller in sec. 11, Sherman Town-

[a] By Frank Leverett.

ship, is 337 feet, and one on the farm of Francis Goodman in sec. 3, 240 feet deep. There are numerous wells 100 to 200 feet in depth in that region. The water in nearly all has very little rise above the level at which it is struck. No wells within the county have ever reached rock, and it is possible that the highest points have 1,000 feet or more of drift. A boring at Reed City on ground only 1,025 feet above tide reached a depth of 276 feet without finding rock, the bottom of the well being nearly 1,000 feet lower than the highest point in the county. No borings in the northern part of the Southern Peninsula have found rock at an altitude more than 900 feet above tide, and it is scarcely probable that any points will be found within the limits of Osceola County at which the rock will reach an altitude of 900 feet. It is more likely to be entirely below 700 feet.

Flowing wells have been obtained in the vicinity of Marion, Rose Lake, Evart, and Reed City, and it is probable that they may be obtained in valleys and on the borders of lake basins in many other places in the county. Those in the southern part were examined by Mr. Fuller, who has prepared a report on them and on the village supplies of the county.

WATERWORKS.

EVART.

The public water supply of Evart is derived from two dug wells approximately 10 feet in diameter and 15 feet deep. They are located near the bank of Twin Creek, the surface of the ground being about 4 feet above the creek bed, about 30 feet above the railroad station according to barometer, and approximately 1,030 feet above sea level. The water stands 4 feet below the surface.

The wells were sunk and the waterworks constructed by the town about fifteen years ago. The pump has a capacity of 1,500,000 gallons per twenty-four-hour day. The domestic pressure maintained is 30 pounds to the square inch; the fire pressure, 80 pounds to the square inch. There are 5 miles of water mains and 30 fire hydrants.

Ordinarily the two dug wells furnish the entire supply of the town, but the amount is somewhat limited and sprinkling is allowed only between the hours of 5 to 8 a. m. and 5 to 9 p. m. The creek, however, can be drawn from in emergencies. A short distance back of the pumping station is a small flowing well, which could be made to furnish 3,000 additional gallons of water daily, but as yet no use is made of it. (See p. 86.) The location is such that additional supplies from shallow wells could be obtained at a very moderate cost. Small supplies from deep wells, similar to the one mentioned, could also probably be obtained at a depth of about 200 feet.

The water from the two wells is low in iron and of only medium hardness. A partial analysis is given in tables on page 91.

REED CITY.

The public supply of Reed City has been from a large dug well, feet in diameter, supplemented by pond water in cases of emergency. The waterworks, which are owned by the city, are located the bank of the mill pond in the northern part of the town, the ell being just back of the pumping station and a few feet above e river. The elevation is approximately 1,005 feet. In 1904 the pply was short, and even with sprinkling hours limited to morning d evening it was necessary to draw from the river. Fifteen new riven wells, to be about 65 or more feet deep, are contemplated 1904), several of which will be located inside of the large dug well nd the rest piped into it. It is expected that the water will rise bout 6 feet above the level of the pond.

The pumps, which have a capacity of 1,500,000 gallons in twenty-our hours, draw directly from the dug well or cistern. The average onsumption is 380 gallons a minute. There are several miles of ains and about 36 fire hydrants. A small supplementary water pply is obtained from a deep well sunk about fourteen years ago. his is not turned into the general supply, but is piped to one or two oughs and a drinking fountain.

The quality of the town water could not be determined at the time the writer's visit, as it was then mixed with lake water. The water the deep well resembles that of the J. H. Andrews well, an analysis which is given in table on page 91.

FLOWING WELLS.

EVART DISTRICT.

What is here known as the Evart district does not consist of a conuous area in which artesian waters are universally found, but ther of a number of isolated wells scattered along the valley of the uskegon River for several miles. (See fig. 22.) These are in the rt of the valley immediately east of the great interlobate moraine rmed between the Lake Michigan and Saginaw Bay ice lobes. This oraine, within 5 miles northwest of Evart, reaches an altitude 300 et above the village, and being composed of loose-textured drift sorbs a large part of the rainfall. It thus seems well adapted to pply strong wells to the districts through which its waters pass nderground. The full exploration of the valley above Evart, especially of the portion north of the river, may yield strong flows supplied om this catchment area. There were in the summer of 1904 only our flowing wells in the district: one at Evart, one in sec. 26, T. 17, . 8 W., one in sec. 23 of the same township, and one in sec. 21, T. 17, . 7 W. During the summer of 1904 E. C. Cannon drilled a well in he flats just south of Muskegon River in sec. 25, T. 17 N., R. 8 W.

In August the well had reached 350 feet, but at that time the tools were lost and the well was abandoned. No flows were encountered.

The only flowing well found in the village of Evart is located in the southwestern part just back of the waterworks, near Twin Creek, at a level about 3 feet above the creek bottom, and very nearly 1,030 feet above tide. It is 195 feet deep, and flows at 1½ feet above the surface. It was sunk about 1901 to supply a proposed fish hatchery. The water is said to have been analyzed and found suitable, but no use has yet been made of it. The yield is said to have decreased, but it now flows 2 gallons a minute from a 2-inch pipe. Its temperature is 48° F.

The water could be turned into the wells of the public water supply without difficulty and would add, if flowing at its present elevation, some 3,000 gallons daily. This flow would probably be considerably increased if it was piped into the waterworks wells at a depth of 3 or 4 feet below the surface.

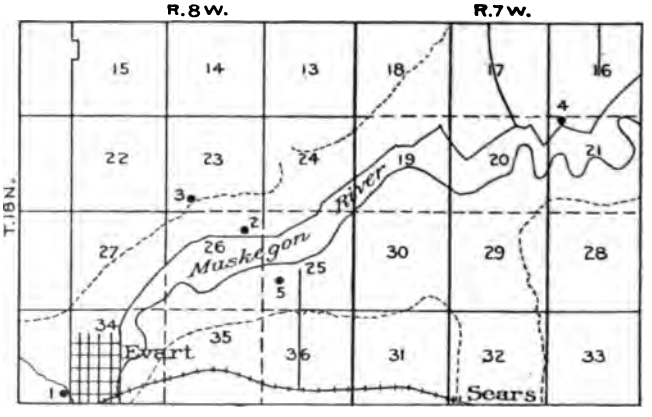


FIG. 22.—Sketch map of Evart artesian district, Osceola County.

The J. K. Grandy well (sec. 26, T. 17 N., R. 8 W.), which is one of the largest drift wells in Michigan, is located on a high terrace bordering Muskegon River, and half a mile southeast from the face of the moraine which crosses the southern half of sec. 23. The well was drilled by Jenkins and others in 1896, and is 2 inches in diameter and about 120 feet deep. No flows were encountered, except the one at 120 feet, which issues from a pipe at about 3 feet above the surface. Its full head has not been measured but is probably considerable, as the water issues with some force, throwing a 2-inch jet 5 feet horizontally in a vertical drop of 3 feet. The yield is 88 gallons a minute, and the temperature is 48° F. The water tastes slightly of iron, is medium hard, and gives a little scale. A partial analysis is given in the table on page 91.

The Henry Baker well (sec. 23, T. 17 N., R. 8 W.) is located on the steep southeast slope of a high moraine, about 35 feet above the

ge of the adjacent flats bordering Muskegon River. The elevation about 1,050 feet. The well is 2 inches in diameter, 60 feet deep, d was sunk in 1901. It yields a flow of 15 gallons a minute at 3 t above the surface, but will rise at least 6 feet higher. The flow said to have been over 75 gallons a minute before the well was pped down to its present small orifice. No decrease of volume s been noted. The flow comes from sand at the bottom, no other w being encountered. The water has no taste, is only medium rd, and gives but slight scale. It is used for dairy, household, and rm purposes.

The Charles Conn well (sec. 21, T. 17 N., R. 7 W.) is located on a t terrace near what is known as the Elbow of Muskegon River. A am giving a flow about the size of a pencil was found at 80 feet. e well was drilled deeper, but, as no other water was found, the sing was pulled back to the first-found flow.

Water is generally found at less than 50 feet throughout the flats, it is not under artesian head, and windmills on deep-well pumps e required to bring it to the surface. The few attempts made to t flows have been generally successful, but, owing to the difference fineness of material and the pinching out of the water-bearing veins vay from the moraine, the results are very variable and can not be edicted. It is probable, however, that along the northern side of e river and within half a mile of the morainal hills, flows could be tained within 200 feet of the surface at most points. A drawback development is the high charges made by drillers in this locality, being cheaper to drive shallow wells and install windmills than to k deeper for flows. More flows could also probably be obtained ar creek level along the stream west of Evart on which the water-orks are located.

REED CITY.

Besides the deep well at the waterworks, mentioned on page 85, e only flowing wells in town are those owned and operated by J. H. ndrews, and situated at the electric-light station, at the foot of the ill pond on the eastern edge of town. At an elevation of about 000 feet are two wells 230 and 168 feet deep, respectively, drilled y Jacob Null in 1902. Small flows were obtained at 40 to 45 feet, ut the water did not rise much above the surface. The wells are cated on the flood plain of the small stream just below the mill pond, about 10 feet below the pond level, and the water will rise from 12 14 feet above the surface. The flow of the deeper well is reported s 105 gallons a minute, and of the shallower as 65 gallons, but they re now cased in and can not be measured. A ram is attached to ne, which raises the water 15 to 20 feet into the electric-light plant nd residence of Mr. Andrews. The water is high in iron and rather ard. *For partial analysis see table on page 91.*

The success of the well at the electric-light plant seems to indicate the possibility of obtaining good flows along the creek below the pond, and smaller flows from a low head could probably be obtained along the border of the pond itself. The head of neither the wells at the waterworks nor of those at the electric-light plant is sufficient to carry the water to the level of the flat on which the town is located, making it doubtful whether flows can be obtained in the business portion of the town, within reasonable distance of the surface.

MARION.

Marion is located in the northeast township of Osceola County near a branch of Muskegon River and east of the morainal hills occupying the greater part of the county. The wells are reported to vary from 20 to 80 feet in depth, the largest supply being at 60 or 70 feet. Some wells are said to have a weak flow, the head being sufficient to lift the water 6 to 8 feet above the surface. A public supply is maintained for fire purposes, but it is proposed to extend it by drawing from a pond. There is also a reported flow in the woods in the northeast corner of the county.

ROSE LAKE.

This village is located in the north-central portion of Osceola County in the hilly moraine. The wells vary in depth from 20 to 80 feet. In some instances the water has a weak flow and will rise about a foot above the surface. The shallow water is reported to be moderately soft, the deep water rather hard.

SPRINGS.

NO-CHE-MO SPRINGS.

The No-che-mo Springs near Reed City rank among the well-known mineral springs of Michigan, the waters being extensively advertised and sold throughout the country. A few years ago an attempt was made to develop the locality into a resort, and the springs were converted into flowing fountains, sometimes of considerable beauty. Over 100 springs are said to be found close together, but many of them are as yet undeveloped. The grounds are laid out with walks and trout ponds, and there is a bottling house of considerable capacity. The No-che-mo Springs are located about a mile north of Reed City in the marshy bottoms along Hersey River. They are mostly situated from 3 to 5 feet above the water level and are po sibly 10 feet above the dam at Reed City. They occur in a sort of shallow amphitheater marking a former meander of the river. The ground is marshy throughout, and the springs are found within an area of a comparatively few acres.

The following is a list of the more important of the developed springs, together with data regarding quality of water, volume, and temperature:

Data of No-che-mo Springs.

Name of spring.	Number of jets.	Total volume.	Temperature.	Taste.
		Gals. per minute.	*° F.*	
No-che-mo Spring	3	3	.....	Strong iron.
Spiritual Spring	3	12	49	Iron.
Osceola Spring	1	4	.....	
Fountain of Youth	4	5	48½	None.
Seven Springs	1	Several.	.....	
Cold Spring Geyser	1	½+	.....	
Good Luck Spring	1	½	49	Do.
Pontiac Spring	1	1	.....	
Three Springs	3	3	.....	
Spring	1	4	.....	Strong iron.

The quality of the water as regards taste has been indicated in the above table. A complete analysis of the No-che-mo Spring, which is regarded as possessing the most valuable medicinal properties of any of the springs, is given below:

Analysis of water of No-che-mo Spring.[a]

[By Richard Fisher and Albert A. Prescott, Ann Arbor, Mich.]

	Parts per million.
Silica (SiO_2)	14.35
Phosphoric acid (PO_4)	.36
Iron (Fe)	2.00
Aluminum (Al)	.48
Magnesium (Mg)	18.36
Bicarbonate radicle (HCO_3)	265.12
Calcium (Ca)	50.04
Sodium (Na)	14.61
Chlorine (Cl)	8.30
	373.62

The water is bottled and extensively sold for table and medicinal purposes, shipments having been made to California and Hawaii. A sort of snuff, said to be very beneficial in cases of cold and hay fever, is made by passing the water through a series of square metallic cans, in which on the bottom a brownish sediment, mainly of the hydrous oxide of iron, collects.

The "springs" as they now exist are really all shallow artesian wells, although most of them were natural springs before being artificially confined by an impervious cover and made to rise through pipes into the fountains. It is reported that in a few instances flows were obtained by simply driving pipes 10 to 12 feet into the ground. The most interesting spring scientifically is the Geyser Spring, the

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

water of which is piped laterally for some distance underground. Most of the time it flows weakly, but about every two hours it is said to throw a jet several feet into the air. This flow continues for five to ten minutes, and then subsides. During the activity of the Geyser Spring the Osceola Spring, which is piped from the same source, stops flowing. The geyser-like activity is probably due to a peculiar method of piping, doubtless some form of siphon action.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Osceola County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Ashton	Driven wells, creeks	20	60	55	55		Large.
Avondale	No returns						
Chippewa station.	do						
Dewings	Driven wells	10	85	40	40		Variable.
Dighton	Driven wells, open wells, and springs.	12	135	100	100		Small.
Evart	Driven wells, springs (flowing wells near).	10	197	50			Variable.
Garmer	Driven wells, open wells	20	100			−20	Do.
Hartwick	Driven wells	20	125	60			Small.
Hersey	No returns						
Ina	Driven wells, springs	160	225	190			Do.
Leroy	No returns						
Marion	Driven wells and river (some flows)	20	80	65		± 0	Large.
Orient	Driven wells, springs, creeks	25	125	75			
Orono	Driven wells	12	35	18	15		Small.
Park Lake	do	12	65				Variable.
Reed City	Driven wells, pond, spring (some flows).	12	200	30		± 0	Medium.
Rose Lake	Driven wells (some flows)	10	80	20	20	± 0	Do.
Sears	Driven wells	20	196	25	25		None.
Tustin	Driven wells, open wells			40			

QUALITY OF WATER IN OCEANA, NEWAYGO, MECOSTA, AND OSCEOLA COUNTIES.

By Myron L. Fuller.

The following table gives miscellaneous analyses made in the field. The field apparatus did not determine the exact amount of sulphates present when there was less than 30 parts per million. The figures are based on estimates and are probably correct within 5 parts per million.

Field analyses of waters in Newaygo County, Michigan, with various conditions.

[Parts per million.]

No.	Town, township, or district.	Location. Township.	Range.	Section.	Quarter.	Source.	Owner.	Color.	Iron.	Sulphates.	Chlorides.	Carbonates.	Page described.
1	Hart	15	17	17	SE.	Public supply (wells)	Town	None	½	Trace.	33	200	59
2	Pentwater	16	18	14	SW.	do	do	do	1	15	22	187	60
3	Summit Township	16	18	1	NE.	Well	Julius Neilson	Very slight amber.	2½	Trace.	8	290	80
4	Weare district	16	17	35	SE.	do	John Lipp	None	½	Trace.	1.5	200	56
5	Crystal Valley	16	16	17	SE.	do	H. C. Lockwood	do	¼	Trace.	1.5	200	54
6	Elbridge	15	16	8	NE.	do	Isaac Timmons	do	1	5	4	200	55
7	Shelby	14	17			Public supply (wells)	Town	do	½	Trace.	11	158	60
8	Shelby district	14	18	25	SE.	Well	Geo. Nelson	do	¾	Trace.	4	166	50
9	do	14	18	36	NE.	do	John Anderson	do	½	None.	4	166	50
10	Evart	19	8	33	SE.	Public supply (wells)	Town	do	¼	None.	15	162	84
11	Evart district	19	8	26	NE.	Well	J. K. Grandy	do	1½	None.	4	187	86
12	Reed City	18	10			Spring	No-che-mo Springs Co	Amber and opalescent.	4	Trace.	16	194	88
13	do	18	10			Well	J. H. Andrews	Slight amber	3	None.	6	200	87
14	Barryton	16	7	27	SW.	do	F. Kunzman	None	¾	None.	20	171	76
15	Mecosta	14	8			Public well	Village	do	1	None.	41	175	78
16	Sheridan Township	15	7	1	SW.	School well	School district No. 1	do	1¾	Trace.	14	242	77
17	Newaygo	12	12	19		Well	Thompson Bro. & Co	do	1	None.	4	200	71
18	Fremont	12	14	2	NW.	Public supply (wells)	Town	do	2	30	9	335	65
19	do	12	14	2	NE.	Well	Hagerdorm's laundry	do	Trace.	Trace.	3	115	66
20	Fremont Lake	12	14	3	SW.	do	H. E. Hain	do	1	Trace.	1.5	240	66
21	Fremont district	12	13	17	SW.	School well	Garfield Township	do	¾	Trace.	6	258	68
22	do	12	14	22	SE.	Well	H. B. Markle	Very slight amber.	2½	None.	4	240	68
23	Hesperia	14	14	30	SW.	do	O. H. Johnson	do	2½	None.	5	240	64
24	do	14	15	25	SE.	do	H. K. Bush	None	½	50	16	222	64
25	Ferry	14	16	23	NE.	do	Jas. Osborn	do	Trace.	Trace.	16	115	57
26	Flower Creek district	13	18	26	C.	do	Julius Fohlbrook	Slight amber	3	None.	9	200	48

WATER SUPPLIES OF ISABELLA COUNTY.

By W. M. Gregory.

GENERAL STATEMENT.[a]

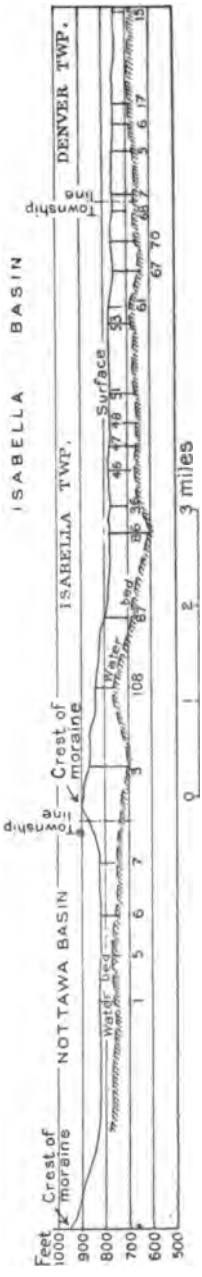


Fig. 23.—Profile of water beds and surface in Isabella County.

Isabella County, of which Mount Plea the county seat, is called the central co the Southern Peninsula. It lies entirely the drainage basin of Saginaw Bay, a covered by the Saginaw glacial lobe. It a concentric series of moraines, runnin curving course across the county, concav east. The drainage has a trellised arran because of the control exercised by th raines. The principal stream is Chippewa which drains the central and northwester of the county. The southwestern part i tary to Pine River and the northeastern River. The Glacial Lake Saginaw exte few miles into the eastern part of the and its bed is now a smooth plain slopin ward. It is on this plain that some of t flowing-well districts here discussed ha developed. There are also flowing-well d in the sags between the morainic ridges

On the moraines wells are often dri depths of 50 feet or more, but as a rul in plenty is found at moderate depths. for the flowing wells, which are sunk order to obtain a flow, it is rare that a we feet in depth. The only wells which have rock are those at Mount Pleasant, know bromine wells, of which there are four sunk to depths of about 1,500 feet. T is between 400 and 500 feet in thick Mount Pleasant, and may exceed 700 fee western part of the county on the high tracts, which stand more than 200 feet the town.

FLOWING WELLS.

GENERAL RELATIONS.

Isabella County has three large flowi districts, which extend into the adjacen ties of Midland and Clare. One dist

[a] By Frank Leverett.

ottawa and Gilmore townships lies between two morainic ridges, hile the other two are on the eastern or lakeward slope of the more .stern of these moraines. The western district is called the Nottawa ·tesian basin; the large district in the eastern part of the county ıd in western Midland County the Isabella basin; and a district nbracing the southeastern part of Isabella and southwestern part ſ Midland the Coe basin, each being named from the township in ·hich flows are most widely distributed and most numerous. In ddition there are two isolated flowing wells in the southwestern orner of Isabella County. The following table indicates the townhips included in each basin, the number of flowing wells which have ɔeen located, and the total flow of 256 of these wells:

Summary of flowing wells of Isabella County and parts of Gratiot, Midland, and Clare counties.

COE BASIN.

County.	Township.	Number of wells.	Area.	Flow per minute.
			Sq. miles.	*Gallons.*
Isabella	Coe (T. 13 N., R. 3 W.)	38	9	66.1
Do	Chippewa (T. 14 N., R. 3 W.)	26	6	130.1
Midland	Jasper [a] (T. 13 N., R. 2 W.)	17	6	89.7
Gratiot	Bethany (T. 12 N., R. 2 W.)	3	2	65.0
		84	23	351.9

ISABELLA BASIN.

Isabella	Isabella (T. 15 N., R. 4 W.)	91	26	216.1
Do	Southeast Vernon (T. 16 N., R. 4 W.)	13	8	27.0
Do	Denver (T. 15 N., R. 3 W.)	25	5	52.4
Do	Wise (T. 16 N., R. 3 W.)	8	2	12.6
Midland	Geneva [b] (T. 15 N., R. 2 W.)	3	3	6.1
Do	Warren [b] (T. 16 N., R. 2 W.)	1	1	.8
		141	45	350.0

NOTTAWA BASIN.

Isabella	Nottawa (T. 15 N., R. 5 W.)	13	6	35.3
Do	Gilmore (T. 16 N., R. 5 W.)	6	3	72.3
Do	Northwest Vernon (T. 16 N., R. 4 W.)	8	11	19.0
Clare	Grant (T. 17 N., R. 4 W.)	4	5	8.1
		31	25	131.7

SUMMARY.

Coe basin	84	23	351.9
Isabella basin	141	45	315.0
Nottawa basin	31	31	134.7
	256	99	801.6

[a] Davis found a flow of about 110 gallons a minute from 52 wells in Jasper Township.
[b] The wells of Geneva and Warren townships are somewhat isolated and may not fall within the Isabella basin.

Isabella Township has the largest number of flows, and the wells are widely distributed, being highly prized by farmers for domestic,

stock, and dairy purposes. The water is suitable for laundry use, although requiring in some cases the addition of softening compounds. In cheese factories and creameries it is used for cooling and makes it possible to dispense with the use of ice. The better methods of well drilling have lessened the cost and led to a great increase in the number in the last five years. The wells cost from 25 to 50 cents a foot and are drilled usually under a contract for a flow. They are allowed to flow freely, not being checked in any of the basins which were visited. There is little danger of a well diminishing the flow of its neighbors by this practice, because they are widely separated, but in time it may result in a general loss of head in the area, and this should be guarded against.

In the western half of Isabella County a supply is secured easily by shallow pump wells, or by deeper wells with water near the surface or even overflowing. The shallow flowing wells yield better water than

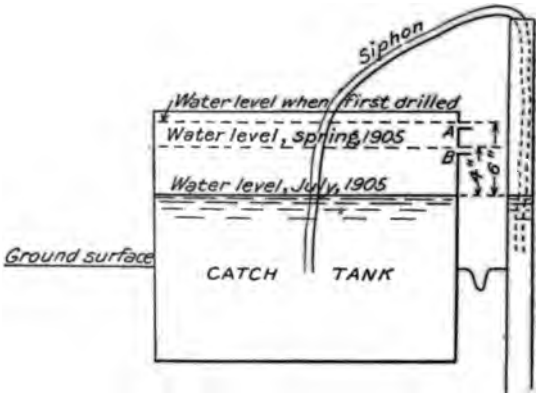


FIG. 24.—Sketch showing fluctuations of Abbott's well, 2 miles north of Shepherd, Coe Township, Isabella County.

the deeper, for the latter are apt to be slightly brackish, a condition found in some of the wells along Chippewa and Salt rivers.

The total flow of the wells in these three districts is about 800 gallons a minute, estimates having been made from 256 wells, which are distributed among the different basins, as shown above. In the Isabella basin the flows average about 2 gallons a minute. Several local failures of the supply were found in this basin, but there was no indication of any general change. In the Coe basin the wells average 4 gallons a minute and show no indications of any general decrease. Mr. Abbott, a well driller, has his well (No. 38, Coe Township) so arranged that its fluctuations have been determined. The well was drilled in 1898, and the head was 6 inches higher than at present (July, 1905). The annual variation in head is 4 inches, being highest in the spring and lowest in the summer, as shown by the sketch (fig. 24), which was made on the ground. It will be observed that the

ıest water level of the spring now falls 2 inches short of reach- the original level when the well was first drilled.

n the Nottawa basin the wells average about 3 gallons a minute, considering Mr. George Cook's well, which flows 60 gallons a min-. None of the wells have shown any decrease, and the probable a from which these flows can be obtained is larger than that now veloped, but it is limited by the moraines on the west and east.

COE BASIN.

In the Coe basin, in the southeastern township of Isabella County, ıd in the bordering parts of Gratiot and Midland counties, the slope

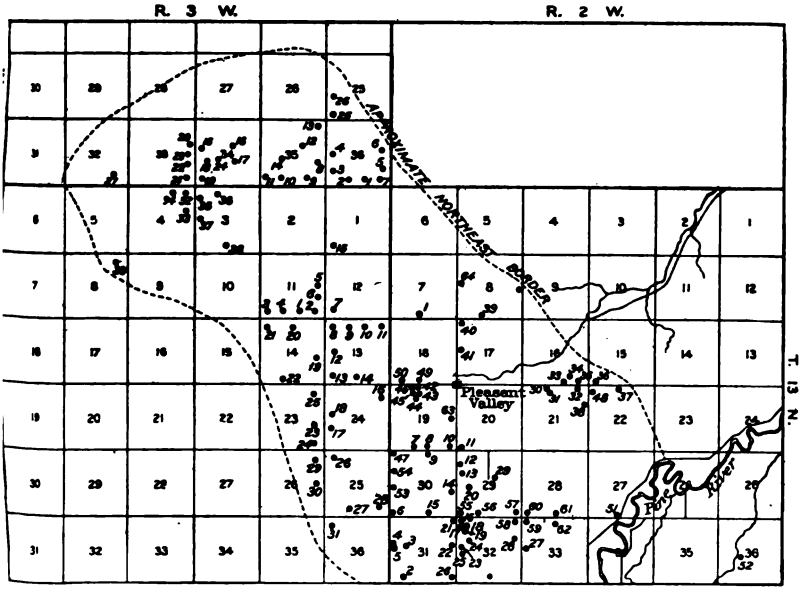


FIG. 25.—The Coe flowing-well district of Isabella and Midland counties.

the water beds appears to be to the east (fig. 25). The western lge of this basin follows, in a general way, the borders of Lake Sagi- ıw, an old Glacial lake, whose beaches in this region are about 750 to 5 feet above sea level. The material from which flowing waters are rived is more sandy than that of the other basins, and considerable ouble is experienced because of clogging and caving, which requires equent sand pumping and repair. Many fragments of drift coal om the Michigan formation are encountered, but no bed rock is ached. The following record of J. L. Coon's well (No. 15, Coe ownship) gives an idea of the material to be encountered:

Record of Coon well, Coe Township.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	20	20
Hardpan	14	34
Sand, gravel, and first flow, weak	44	78
Hardpan	10	88
Sand, gravel, and second flow, weak	10	98
Reddish clay above blue below; water in gravel at 205 feet	117	215

Mr. Abbott (No. 38, Coe Township) drilled three wells on his property, 205, 105, and 87 feet in depth, respectively. The last one flows a small stream, which fluctuates during the year. The deeper wells were some 200 feet distant from the flow, and, after passing through 50 feet of sand and gravel, the remainder was red and blue clay. In the northern part of the Coe basin, in Chippewa Township, Mr. Salisbury's well had the following record:

Record of Salisbury well, Coe basin.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	32	32
Hardpan and clay	53	85
Sand, with some water	12	97
Soft blue clay; flow from gravel under clay	15	112

Mr. Salisbury has an abundant supply of water, which is forced to the second story of his residence by a hydraulic ram. The well has been cased 97 feet. In the Coe basin, Midland County, the well owned by Mr. W. H. Fox (No. 18 Jasper Township, Midland County) found water-bearing beds at 40 feet and 55 feet, and the present supply, under hardpan, at 84 feet. The Coe basin extends south nearly to St. Louis, Michigan (see report by C. A. Davis, pp. 219–220).

JASPER TOWNSHIP (T. 13 N., R. 2 W.), MIDLAND COUNTY.[a]

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed. Elevation.	Water bed. Character.	Flow per minute.	Temperature.	Quality of water.	Remarks.
			Feet.	In.	Feet.	Feet.	Feet.		Galls.	°F.		
7	C. Baker				60			Sand				Wells about this depth along this road.
31	N. S. Baldwin				120	+ 1			0.5	50	Rather hard	House well, pump, dug, shallow, water soft.
31	A. W. Baldwin	1897	740		70	+ 1.75	670	Sand	2		do	Not flowing, filled with sand.
	do	1897	740		50	+ 1.5	690	do	5		do	Flow too small, now pumped.
	do		740		20	+ .5	720	do	.25		do	Head formerly 14 inches higher.
30	A. J. Austin	1901	730 725G		76	+ 1	654 649G	Gravel	.25	51	do	
19	L. A. Pierce	1880	728		17	+ 1.5	711	do	1G	50G		
19	Geo. Smock	1885	728		32	+12	696	Sand	1.12	52	Rather hard	Formerly flowed 3 gallons a minute; needs sand pumping.
30	T. D. Martin	1896	725		32±	+ .3	693	do	1		do	
19	Willis Smart		730			+ 1.33		do	3	50	do	
20	N. Johnson		730		140?	+ 2	590	do	.25	51	do	J. Tuger, owner of farm.
29	J. Tuger		730		50	+ 3	680	do	.25	51	do	
29	G. Roberson		730		47	+ 2	683	do	4	50	do	
30	M. Roberson	1889	730		41	+ 2	689	do	2	50	do	
30	R. C. Martin	1884	725 728G		42	+ 4	683G	do	3	50	do	
32	M. Roberson	1889	725		43	+ 4	682	do	2	50	do	Cost $15.
	do		725		76		649	do	8-10		do	
	do		725		55		670				do	
	do		725		32		693				do	
29	W. Hanley		730		63	+ 3	667				do	Barn well No. 20; house well No. 21.
31	do		730		90	+ 1.5	640				do	
31	R. Bobazine		725		90	+ 4	635	Sand	1	50	do	Head 10 feet when put down.
32	J. Zimmerman		728		50	+ 3	678	do	2	50	do	House well No. 23; barn well No. 24.
	do		728		86	+ 2.5	642	do	2	50	do	
	do		725		87	+ 2.5	648	do	2-3		do	
31	George Carter		715		53	+ 1.5	662	do	8		do	
33	W. Billock		710		80	+ 2	630	do	1		do	
32	J. W. Fox	1903	718		60	+14	658	do	.5		do	Cost $20.
29	F. Preston	1901	725		20	+ 1	705	do	33	50	do	
21	C. Brown	1884	720		32	+ 1	688	do	Small		Hard; iron	These two wells are intermittent flows and stop in the dry season.
	do	1884	720		33	+ 1	687	do	do			
16	W. Keefer		720		66		654	do	do		do	Formerly flowed more, but stopped recently because of sand.
16	Myron Keefer	1895	718		33	+ 2.5	685					Well is now pumped.
	do	1895	720		33	+ 0	687					Flows into crock and is dipped out.
15	Geo. E Brown	1890	720		42	+ 2	678	Sand	3	50.5	Hard	Flows at 21 feet also.
15	L. Pickens		722		33	+ 2	689	do	1		do	

[a] Data chiefly from C. A. Davis. The letter "G" after certain figures indicates that they are furnished by W. M. Gregory.

Wells in Coe basin—Continued.

JASPER TOWNSHIP (T. 13 N., R. 2 W.), MIDLAND COUNTY—Continued.

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed. Elevation.	Water bed. Character.	Flow per minute.	Temperature.	Quality of water.	Remarks.
			Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*		*Galls.*	*° F.*		
22	L. Orwig	1900	715	....	65	+ 2	650	Sand	1	.....	Hard	
21	E. Stevenson		715	....	60±	+ 2	655	do	1.5	50	do	
8	E. Hartford	1898	725	....	42	+ 1.5	683	do	8	50	do	
17	J. McDougal		724	....	47±		676					
17	E. Sheldrake		720	....	87		633					
19	Old Turner place[a]		725	....	16		709					These five wells (Nos. 42 to 46) are not cased to bottom, and flow some of the time. When one is pumped for a short time, the others cease flowing until the pumping is stopped.
	do		725	....	27		698					
	do		725	....	28		697					
	do		725	....	25		700					
	do		725	....	30		605					
30	A. T. Shively[a]	1884	727	....	40		687					
22	M. Milligan[a]		722	....	50+	+ 2	672	Sand	4	50	Hard	
18	R. Turner[a]		725	....	26		699					Small flow.
18	Doctor Seares[a]		725	....	33		692					
27	School district[a]		705	....	90?	+ 2	615		2	49.5		
36	Ward (sawmill)[a]		727	....	30±	+ 2			2			Located in creek valley at sawmill site.
	E. Ostweld[b]		725	2	80		645		.8	50		House use.
	R. Martin[b]		728	2	60		668		1.5		Soft	House and barn.
	G. Smock[b]		730	2	20		710		.7	50	do	Do.
	H. Buletz[b]		710	2	80		630		.6		do	House use.
	George Gleeker[b]		716	2	50		666		.7	50		House and barn.
	F. Ostweld[b]		717	2	29		688		.9	49.5	Soft	In field for stock.
	Wm. Hanley[b]		715	2	50		665					Small flow at house.
	J. Hanley[b]		710	2	30		680		1	49.5	Soft	House use.
	M. Pierce[b]		725	2	20		705		1			House and barn.
	H. Bailer[b]		715	2	45		670		1.5			In field for stock.
	Tuger & Son[b]		720	2	25?		695		10	49		Do.
	O. Edwards[b]			2	38				1.5		Soft	House use.

COE TOWNSHIP (T. 13 N., R. 3 W.), ISABELLA COUNTY.

	M. O'Boyle		747	....	80	+20	667		7	51	Soft	Stock.
	E. Rivett		747	....	130		617		3	51	do	House and barn.
	M. Farran		747	....	43		704		.5			Stock.
	do		747	....	66		681		2	51		Do.

G. Mills		740	51		689	1		Soft	Do.
W. E. Warner		742	60		672	1	50		
J. E. Coon		727	205	+ 4	667	1	50		House and barn.
D. Peters		725	70		655	2			Mostly clay; flow at 20 feet.
E. Frost		738	30		708	1		Soft	House and barn.
B. Trop		738	40		698	1.5	50		Domestic and piped to field.
R. Elliott		739	80		659	1	50	Soft	House use.
A. Clay		747	80		667				
M. Farran		749	92		657	1		Soft	Do.
W. B. Brooks		750	58		692	2		do	
R. Converse		743	88		655	1		do	Field and barn.
George Ross		730	30		700	1		do	
Chas. Boyden		745	92		653	1.5		do	House use.
H. Davenport		730	26	+ 9	704	.5		do	Weak flow.
Mrs. Hart		730	50		680	2.1		do	House use.
O. Bush		725	89		636	1		do	House and barn.
Mr. Dutt		746	25		721	1.5		do	Three wells on farm for stock.
A. Blenker		745	35	+ 7	710	2		do	House use.
H. G. Leonard		735	20		715	.5		do	House use; weak flow.
C. Freeman		766	50		716	1.5	49	do	House use.
Wm. Church		760	46		714	2	49	do	House use; no softening compounds used.
J. Robinson		777	80		697	2	49	do	Two flows.
J. Slates		767	50		717	2.5	49	do	At house; piped to barn.
Wm. Florence		735	50	+14	685	2.5	49	do	House and barn.
J. Kingsbury		766	60		706	3	49	do	House and field.
A. Abbott		730	87	+ 1	643	1	49½	do	Rate of flow varies.
R. E. Myers		790	74		716	2		do	Only 18 feet of pipe in well.

[a] Records furnished by Mr. Armstrong Kinney, well driller, from memory.

[b] Data by W. M. Gregory.

Wells in Coe basin—Continued.

CHIPPEWA TOWNSHIP (T. 14 N., R. 3 W.), ISABELLA COUNTY.[a]

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed. Elevation.	Water bed. Character.	Flow per minute.	Temperature.	Quality of water.	Remarks.
			Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*		*Gall.*	*° F.*		
	P. Allen		715	2	50 47	+10	665 668		1	48	Hard	House and barn.
	N. Hill		718	2	71? 60		647 658		1			Do.
	S. J. Allen		715	2	86	+11	629		2	49		Do.
	B. Gardiner		710	2	76	0	634					Clogged by sand; weak flow.
	H. R. Kelley		710	2	36		674		1.5	48		House use; mostly clay.
	H. Reeves		712	2	82	+13	630		3			Stock use.
	E. Y. Kelley		710	2	80	+15	630		8			House and barn.
	E. P. Peat		719	2	57		662		2	49½	Soft	House, piped to barn; flow decreasing.
	E. J. Doyle		721		70		651		1.5			In field for stock.
	W. D. Seeley		720	2	62		658		2.5			House use; water from under hardpan.*
	A. Strauble		721		62		659		3			House use.
	G. Johnson		715	2	89		626		1	48½	Hard	Not suitable for washing.
	Mr. Mullett		707						2			Stock use and house.
	A. Hixon		718	2	76	+11	642		12	48	Hard	Heavy flow found under 5-foot bed of hardpan.
	B. Wing		730	2	80		650		3			Sand 12 feet, remainder clay.
	D. Johnson		718	2	46		672		5		Hard	House use.
	D. Hall		719	2	76		643		2			Hardpan and clay; no sand.
	F. Vandecar		720	2	30		690		1			House use.
	B. Wing		730		64	+12	666		10	48½		At stock barn; good flow.
	Geo. Harris		738	2	54		684		1.5			In field for stock.
	M. Curran		735		20 35		715 700		2		Hard	House use.
	J. Kern		725	2	36 15		689 710		10 3		 49½	Do.
	W. B. Wing		722		28	+14	694		40		Soft	Barn, for stock use.
	J. Sioux		720	2	49	+13	671		4	49½	do	House use.
	F. C. Coomey		710	2	100	+6	610		1			House use and stock.
	B. Walters		705		90	+12	615		5.1		Hard	Barn and house.
	E. Salisbury		685	2	112		573		2	50	do	Low ground on river flat.

[a] Wells Nos. 9, 11, 13, 19, 21, 23, and 26 have a diameter smaller than 2 inches.

ISABELLA BASIN.

The water beds of the Isabella basin yield small, uniform flows. e beds extend eastward from the crest of the moraine which sepa- es it from the Nottawa basin into the western townships of Geneva l Warren of Midland County, and are distributed over the grad- slope of the plain on the lakeward side of the moraine (fig. 28, 107). Along the western border of the basin many trials have n made to obtain water, but when the elevation is above 820 feet ws have never been obtained, and on the morainal crest the water very scarce. In sec. 7, Isabella Township, several trial wells from to 191 feet deep have failed to secure sufficient water, and the gest part of the material drilled through was tough clay. This perience has been repeated at a number of places on the western rder of the Isabella basin, as shown by the records of Nos. 3, 35, 2, 104, 105, and 108 (Isabella Township). One of the strongest ws in the basin has 30 feet of clay, 18 feet of hardpan with peb- s and gray clay, and 16 feet of consolidated sand and gravel over

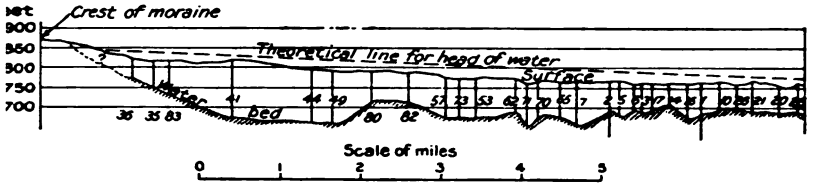


FIG. 26.—Cross section from Isabella to Denver Township.

water bed. In the eastern extension of the Isabella basin, in nver Township, beds are found under the same conditions. The lowing record of George Cole's well (No. 2, Denver Township) is pical:

Record of Cole well, Denver Township.

	Thickness.	Total.
	Feet	*Feet.*
nd	5	5
ay	22	27
and	20	47
lay with pebbles	10	57
and and gravel	15	72
lardpan	1	73

No rock has been reached in any of the wells. Mr. Mal Bloom drilled a well (No. 22, Denver Township) 200 feet without reaching rock, and the water was so scarce that the pipe was pulled back to a small flow at 28 feet. In this well the material was clay under 90 feet of sand and gravel. Several wells of this region are quite high in chlorides, but no rock has been revealed by any of the trials. Several large springs, some of which are salty, occur in this basin along *Salt River. One of the "salt licks"* is in the northwest cor-

ner of sec. 23, Denver Township. A number of these salty spı are found farther east along the river in Geneva Township, Mid County. The wells in the southeast corner of Vernon Townshi in the Isabella basin, as are those to the east in Wise Towns The crest of one of the Saginaw moraines is the western borde the Isabella basin in Vernon, where the water beds range from 1 88 feet below the surface and is scarce in the lower bed and r abundant in the upper layers. Flows ought to be obtained at place in sec. 24, 25, 26, 35, and 36, Vernon Township, and in V Township good flows will be found at moderate depths in secs. 30, 31, and 32. The limit of the bed to the east in Midland Cou has not been determined, but at Coleman a test well 300 feet was made for water, and the material passed in drilling was repo as sand at the surface and the remainder clay. No shallow have an abundant supply of water at Coleman, and driven 100 to 180 feet deep have only a scant supply. Excellent flows reported about Coleman in secs. 7, 11, 16, 17, and 18, Geneva To ship. Northeast of Coleman, Edenville Township, a few have reported, showing that the belt of flows, of which the Isabella the Coe basins are parts, is nearly continuous along the slope of Saginaw moraine from St. Louis, in Gratiot County, through bella and Midland to Gladwin County, near Highwood, and th past Bourrett Township to West Branch, in Ogemaw County.

Wells in Isabella basin, Isabella County.

DENVER TOWNSHIP (T. 15 N., R. 3 W.).

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*		
1	Wm. Brophy	770	150	620	.....	2	49½	.....	House and barn.
2	Mr. Hommell	765	60	705	.....	.5	.....	Hard	House use.
3	P. J. Marty	760	65	695	.....	1.2	51	...do	House and barn: 2 wel
4	.....do	751	80	671	.....	.3	.....	...do	Stock farm; salty wat
5	J. Epple	765	82	683	.....	1.1	.....	...do	House use.
6	J. Lloyd	760	65	695	.....	2.5	51	...do	Storeroom for butter.
7	R. Harrison	765	105	660	.....	1.5	51	.....	At barn, for stock.
8	S. Sherbeneau	760	65	695	.....	2	50	Hard	House use.
9	A. Muterspaugh	760	77	683	.....	1.5	50	.....	Decreased by No. 8; hou
10	Wm. Brown	765	64	701	.....	.....	.....	.....	House use.
11	George Cole	760	73	687	.....	1.9	49	.....	Used for drinking at s
12	Mrs. P. Epple	769	50	719	.....	1.2	.....	.....	House use.
13	J. Day	765	115	650	.....	.....	.....	.....	In field, for stock; no
14	T. T. Tompkins	760	50	710	.....	2.3	.....	.....	
15	Wm. Blendheim	759	70	689	.....	4.5	48½	.....	House; drinking and c
16	Mrs. Monroe	760	81	679	.....	1.2	49	Salt...	Used for drinking only
17	Fred Thorpe	760	60	700		2.4	.....	Hard	House and barn.
18	Mr. Spalsbury	750	30	720		1.5	48½	.....	At house on river flat.
19	P. Goether	755	50	705		2.5	.....	.....	At barn, for stock.
20	O. Allen	755	60	695	.....	3.6	49½	.....	Domestic and stock us
21	George Cole	765	78	587	.....	1.8	.....	.....	House.
22	Wm. Bloom	758	92	666	.....	1.2	.....	.....	Domestic and stock us
23	Mal. Bloom	763	28	735	.....	2.5	48½	.....	House and stock; no w 200 feet.
24	J. Mahon	765	125	640	.....	5.6	.....	.....	House and stock.
25	J. Granger	760	64	696	.....	2.3	.....	.....	Do.
26	Joe. Bloom	760	55	705	.....	1.5	.....	.....	Do.
27	Geo. Loylard	755	60	695	.....	3.8	49	Salt...	Stock and domestic us

Wells in Isabella basin, Isabella County—Continued.

ISABELLA TOWNSHIP (T. 15 N., R. 4 W.).

ner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
	Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*		
ı	870	30	840				Hard	No flow; water scarce.
ı	870	130	740					
ı	866	160	706					No water; all clay.
mill	780	130	630	789	0.5	49½	Hard	Decreased since 1901.
son	770	104	666		.3		do	Do.
	780	150	630		.1	49½		Small flow.
	785	115	670					No flow; little water
ıne	783	100	683		2	49½		House and barn.
b	789	50	739	795	.9			House use.
c	770	100	670		1			Do.
rick	778	90	688		1	49½		House and barn.
hlin	771	75	696		.8	48½		House use.
ips	775	90	685		1.5			Stock and house use.
ɔn	778	100	678		2.5			All clay to water bed.
	780	90	690		1			Stock use.
ıe	782	180	602		1.1			House use.
ing	775	106	669	790	1.5	49½	Hard	Decreasing.
er	775	142	633		1.5			House use.
	777	100	677		2.5	50		Drinking.
n	780	90	690		1	49		House use.
	770	160	610	770				Weak flow; decreasing.
older	772	40	732		1.5	49		Weak flow.
	765	95	670					House use.
	765	80	685		3	49½		At barn, for stock.
	760	100	660		1.5			House and stock.
ll	763	100	663		1			House use.
rick[d]	770	90	680		.9		Hard	In field; only 8 feet of pipe
ight	778	100	678		.5	51		Mostly clay; water hard.
ıam	780	150	630		2.1	50		House use.
ɔn[e]	780	115	665		3.5			House and stock.
	779	90	689		1.5			House use.
	788	180	608		2.6			Stock barn.
	796	90	706					No flow; little water.
	808	100	708	820	.8	49½		Flow decreasing; water hard.
(?)	815	70	845					Pump well.
	829	53	776		2.8	49		House.
s	820	55	765		3.2			House and barn use.
ɔy	821	82	739	818				
ıson	810	200	610					Water scarce.
	798	100	698					All clay; no flow.
ards	820	146	674		4.2	50		House and barn.
ray[f]	783	64	619	801	30	49½		Domestic and stock use.
	782	120	662		5.2			In field.
	794	130	664		3.2	49½		House use; water soft.
y	784	110	674		2	49½		House and barn.
ı	780	98	692		1.3	49½		House use; water soft.
h	779	105	674	790	4.2	49		3 wells.
er[i]	770	100	670		2	50		
ne	790	120	670		.5			
r	790	103	687		1.3			
r	790	100	690		2.5	49½		
hurst	795	90	705		1.5	48½		In field; water soft.
rt	777	90	687		2.5			Stock barn.
ell	778	97	681	785	2.1	50		House use; water soft.
	778	92	686		1.5			In field for stock.
	770	80	690		1		Soft	House and barn use.

s for water have been made here, depths varying from 90 to 193 feet. The water is scarce
. Most is present at 98 feet. Largest part of material is hard clay.
through sand and clay to water bed at 50 feet and continued to 100 feet in hopes of strong
found at deeper point. Pipe pulled back to flow at 50 feet.
remainder sand. Gravel at 100 feet, good flow.
stock use. Only 8 feet of pipe drilled through the hard clay to gravel bed. Flow has

vered No. 91 across the road on the property of Wm. Graham.
se. Record: Clay 30 feet rdpan and gray clay, some pebbles, little water, 18 feet,
nd and gravel, 16 feet; wa er at 64 feet, strong flow nd has been difficult to control;
utside of pipe. Much CO_2 some iron; water is hard.
and flows at 50, 90, 90 feet.
se 105 feet lowered head Nos. 46, 45, and 31. Two other wells same elevation as well
) feet and 95 feet, respectively. Combined flowage of wells exceeds 4.2 gallons per second.
hard.
in gravelly clay. Three feet of hardpan at about 96 feet. A small water bed at 85 feet.
et in pipe.

Wells in Isabella basin, Isabella County—Continued.

ISABELLA TOWNSHIP (T. 15 N., R. 4 W.)—Continued.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*		
57	F. Polwalker	.....	90	.....	.....	1.8	50	.....	House use.
58	Joe Bradley	760	85	675	.....	2.5	.....	.....	Do.
59	D. Riegle	765	104	659	.....	3	49½	.....	House and stock use; soft.
60	Wm. Pfohl	759	100	659	.....	2.1	.....	.....	House use.
61	John Johnson	775	29	756	765	.....	.....	.....	Pump well; water sof
62	J. Develin	770	86	684	.....	5.8	.....	.....	House use.
63	J. Harrison	759	97	662	.....	.....	.....	.....	In field, for stock.
64	Peter Mahan	760	84	674	.....	1.6	.....	.....	House use.
65	J. Harrison[a]	760	80	680	.....	1.5	.....	.....	Stock barn.
66	C. Goodsell	759	110	649	769	8	49½	.....	Decreased by well c feet.
67	Chas. Cooper[b]	750	114	636	.....	8	51	.....	In heavy gravel bed.
68	J. Gallagher	749	60	689	745	1.2	51	.....	House use; water har
69	Wm. Kellar	747	100	647	.....	1.3	51	.....	Stock and house.
70	Wm. Watson	770	93	667	.....	1.5	.....	Hard	Water from sand bed.
71	J. Watson	760	100	660	.....	2	.....	...do	Stock barn.
72	Wm. West	763	80	683	.....	1.5	49½	Soft	In field, for stock.
73	M. Murphy	770	90	680	.....	1	.....	.....	Decreased since drilli
74	J. Conway	780	90	690	.....	2.1	49	.....	In field, for stock
75	J. Mang	783	44	739	.....	.9	.....	.....	Barn.
76	School	780	38	642	.....	1.3	49½	Hard	Drinking.
77	F. Wright	770	44	626	.....	2.1	50	... do	House and barn.
78	F. J. Clare[c]	767	83	684	775	1.4	49	...do	House.
79	Ed. Roberts	771	80	691	.....	2.5	.....	...do	House use; nearly all
80	J. Hobson	790	68	722	.....	.2	48	...do	Barn and house; wat gravel bed.
81	A. Catlin	778	40	738	.....	3.6	48	...do	Stock barn; piped to
82	F. Roy	785	97	688	805	4.1	.....	.....	House and barn.
83	P. Folley	813	89	724	.....	1.1	50	.....	House use.
84	Wm. Elliot	800	90	710	.....	1.2	51	.....	Stock, in field.
85	I. R. Vincon[d]	815	186	629	.....	1.5	50½	.....	House and barn.
86	M. Johnson	775	170	605	.....	2.3	50	.....	
87	W. Swindlehurst	795	100	695	.....	.8	.....	.....	Formerly good flo drained by No. 47.
88	Rosebush station	770	148	622	.....	1.6	.....	Hard	Drinking and steami
89	Joe Horn	772	201	571	.....	1.1	.....	...do	House use.
90	Mr. Neiland	785	60	725	.....	.....	.....	.....	No water; mostly cl
91	Wm. Graham	788	90	698	.....	1.2	.....	Hard	Stock and domestic
92	J. Potter	780	93	687	.....	1.3	50	.....	Domestic use.
93	M. McGuire	770	80	690	.....	1.5	.....	.....	At barn; piped to h
94	School	781	38	743	.....	.3	51	.....	Drinking.
95	Mrs. Beatha	773	38	735	.....	.....	.....	Hard	House.
96	J. Kellar	768	50	718	779	1.8	50	...do	Barn and house.
97	J. Roy	760	70	.....	.....	.....	.....	.....	No water; several tr
98	Ed. Roberts	753	130	623	778	8.2	49½	Hard	House use.
99	J. Campbell	748	50	698	.....	1.5	.....	.....	Clay 25 feet, sand clay 15 feet.
100	Chas. Campbell	745	115	630	.....	2.8	.....	.....	Domestic use.
101	Pat. Garwin	815	80	735	.....	1.5	.....	.....	House use.
102	F. Miller	800	30	770	800	.....	.....	Soft	Pump well in sand.
103	J. Brooklins	790	80	710	.....	9	49	...do	House use.
104	E. Van Buren	810	30	680	.....	2	.....	.....	Do.
105	O. F. Dart	815	30	685	829	5	.....	.....	Barn and house.
106	Lyman Munger	700	157	603	.....	1.5	.....	Hard	House, piped to bar
107	Wm. Bellinger[e]	793	60	733	.....	3	.....	.....	House use.
108	Jas. Daley	840	70	770	790	.....	.....	.....	Pump well.

[a] Two water beds passed before this flow. Drift chiefly clay and gravel. Flow not as s formerly.
[b] Good flow. Mostly clay. Small flow at 70 feet.
[c] Said to be all clay to 60 feet, remainder quicksand. Much iron deposit and algæ.
[d] Record: Sand and gravel, 40 feet; clay, 70 feet; sand and gravel, 75 feet.
[e] Water at 32 feet. All clay.

Wells in Isabella basin, Isabella County—Continued.

WISE TOWNSHIP (T. 16 N., R. 3 W.)

	Owner.	Elevation.	Depth.	Elevation of water bed.	Water se to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*° F.*		
1	James Owen	760	85	675	770	1.8			House and barn; water hard.
2	M. McGuire	764	113	651	778	2.3	48½		House.
3	Dan Walker	760	46	714	770	1.5			In field, for stock.
4	Jas. McConnell	762	45	717	765	1	49		House use.
5	W. Sharp	70	67	703	780	2	48		Do.
6	Geo. Hersey	779	70	709	719				Mostly clay; some sand at top.
7	R. McConnell		58			2.5			House use and stock.
8	C. L. Recher		60?			1.5			Decreased since drilling in 1900; water soft.
9	M. Mannery	750?	151		755?				Little water.

VERNON TOWNSHIP (T. 16 N., R. 4 W.), SOUTHEAST PART.

8	A. McDonald	800	27	773	815	1.8		Hard	House use.
9	T. Ragan	789	15	764	799	2	49½	...do	Flow from gravel under clay.
10	S. Leight	778	39	739		2		Soft	House use.
11	P. Mahar	790	25	765		3	48	...do	Water from sand under 20-foot clay bed.
12	G. Sterne	795	32	763	803	1.5		...do	House use.
13	F. Battle	809	27	782		1.6	49	...do	Water from gravel under clay.
14	R. McConnell	785	58	727		2	48	...do	House and barn.
15	F. Battle, jr	786	25	761	794	4.5	48½	...do	Water muddy before storm.
16	C. McElhenery	790	25	765		2.8			Barn and house.
17	J. Crawley	800	88	712					Failed to get flow.
18	J. McGuire	768	30	738		1.5	48½	Hard	House use.
19	John Owen	788	31	757	798	2.3		...do	House and barn use.
	W. Sharpe	770	60	710		2	49		House use.

NOTTAWA BASIN.

The limits of the Nottawa basin in Isabella County are roughly determined by the moraines of the Saginaw ice lobe, and the few wells already drilled show the water beds to be entirely in the drift. In the northward extension of the Nottawa basin Mr. S. A. Gleason has drilled a well in sec. 35, east of Clare village, Clare County, which has the following record:

Record of Gleason well, Nottawa basin, Clare County.

	Thickness.	Total.
	Feet.	*Feet.*
[illegible]d	20	20
[illegible]vel	2	
[illegible]d	30	22
[illegible]vel	15	52
[illegible]d	25	67
[illegible] clay	10	92
[illegible] clay	31	102
[illegible]ter in gravel		133

In the northern extension of the Nottawa basin in Grant Township, Clare County, at a small sawmill south of Dover post-office, near the east quarter post of sec. 11, the water beds have been reached by three small flowing wells, as shown in fig. 27.

The water bed of sand and gravel is reached by wells A and B, 300 feet apart, with depths of 39 and 28 feet, respectively. In well B the water rises 16 feet in an open pipe and in A it rises 5 feet. If well B is opened and allowed to run twenty-four hours, the head in well A slowly decreases and the flow stops. These changes do not affect the 18-foot well which is half-way between the two deeper wells, and in which the water rises 20 feet in an open pipe. The July temperature of the deeper wells is 48° and that of the shallow well is 47°. The flow of the deeper well is 1.2 gallons a minute. The water of all the wells is soft and suitable for boilers and domestic purposes. To the

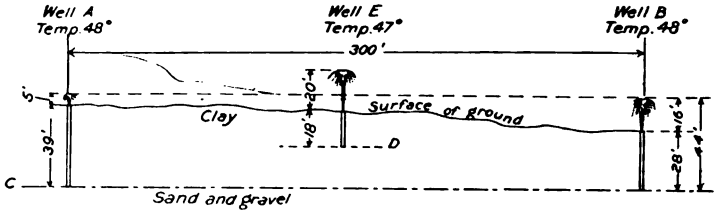


FIG. 27.—Relation of wells near Dover, Clare County.

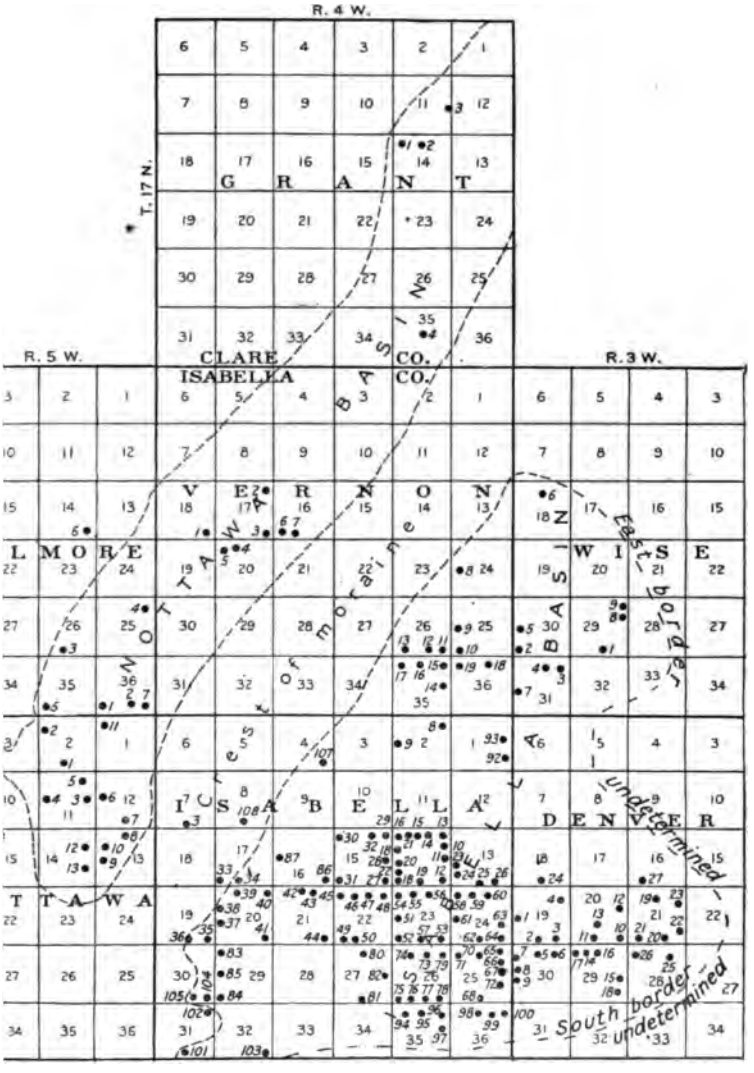
west of the wells for one-fourth of a mile are hills of clay and sand, the tops being 35 feet higher than the mill, and this probably is the catchment area of the beds.

In Isabella County the Nottawa basin does not extend farther south than the lower tier of sections in T. 15 N., R. 5 W., and it takes in the southeast corner of Gilmore and the northwest half of Vernon townships. Duncan's well (No. 4, Vernon Township) is a good representative of this part of the basin which is between the well-defined Saginaw moraines.

Record of Duncan well, Isabella County.

	Thickness.	Total.
	Feet.	*Feet.*
Gray clay	50	50
Hardpan	.5	50.5
Clay and gravel	3	53.5

; on the eastern and western edges of this basin pass through
clay under a covering of sand and gravel. Water is very



—The Nottawa flowing-well district in Isabella and Clare counties, and the Isabella flowing-well district, Isabella County.

Wells in Nottawa basin.

NOTTAWA TOWNSHIP (T. 15 N., R. 5 W.), ISABELLA COUNTY.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Feet.*	*Feet.*	*Gals.*	°*F*		
1	Anna Parish	835	60	775	.....	1.2	.....	Hard	House use.
2	M. Riley	845	34	811	855	2	.....	...do	For house use and pip barn.
3	Wm. Burch	815	40	775	.....	2.5	48½	...do	For stock.
4	M. Palmer	840	38	802	.....	2.1	.....	...do	House use and milk hou
5	F. Cotter	825	60	788	.....	1.8	.....	...do	House and barn.
6	D. Cotter	820	70	750	.....	3.1	.....	...do	Do.
7	A. Kiblebeck	820	60	760	835	4	49	...do	House use.
8	L. Kennedy	830	90	740	.....	3.1	49	.....	House use and stock.
9	Jas. McGuirk	830	47	780	.....	2.1	49	Soft	Water muddy before st
10	M. Doerr	822	47	775	832	4.1	.....	...do	House and barn.
11	A. C. Seymour	810	50	760	.....	2.1	49	Hard	House use.
12	Mrs. Blundy	828	14	804	.....	3.2	.....	.....	House.
13	W. Garber	830	29	801	.....	.5	.....	Hard	At house.
14	J. Lay	860	180	680	.....	.....	.....	...do	No flow (?).
15	J. Doerr	835	67	768	848	3.5	49	...do	

GILMORE TOWNSHIP (T. 16 N., R. 5 W.), ISABELLA COUNTY.

1	G. Cook	830	50	770	850	60	48½	Soft	House use.
2	C. Scofield	815	50	765	820	4	.....	.....	Two wells. Barn for s
3	School	830	48	772	.....	1.5	48½	.....	Drinking.
4	G. W. Gordon	820	30	790	828	2.3	48	Soft	House and barn use.
5	T. T. Wood	840	.....	.....	.....	3.5	48	...do	A spring piped to road.
6	H. Glass	850	200	650	650	.....	.....	.....	Very little water.
7	C. Scofield	815	35	780	.....	1	48	Soft	At house.

NORTHWEST VERNON TOWNSHIP (T. 16 N., R. 4 W.), ISABELLA COUNTY.

1	School	860	24	736	872	1.3	48	Soft	Drinking.
2	W. Warren	850	30	820	.....	2.3	.....	.....	All clay; flow in gravel
3	F. Loomis	862	30	832	.....	1.5	.....	.....	Stock barn.
4	Wm. Duncan	850	54	796	869	9.5	48½	Medium.	Drinking fountain. I and barn.
5	J. Hodkins	850	50	800	.....	1	.....	Hard	House use.
6	S. Thrower	866	40	826	876	2.1	.....	.....	House use and piped to
7	L. Simpson	870	49	821	.....	1.3	49	Hard	House use.

GRANT TOWNSHIP (T. 17 N., R. 4 W.), CLARE COUNTY.

1	Randall school	878	60	818	891	1.5	48	.....	Drinking purposes.
2	Chas. Perry	880	60	820	895	2	48	Soft	House use.
3	Sawmill and house	900	.....	.....	.....	1.6	.....	Hard	
4	S. A. Gleason	848	133	715	861	3	.....	...do	Do.

NOTE.—The wells in the Nottawa basin are all 2 inches in diameter.

ISOLATED FLOWS.

Boyden.—The "magnetic mineral" flowing well, near Boy Deerfield Township, was obtained in prospecting for coal on the f of Mr. W. Wykes in October, 1897. The drillers had reached a d of 168 feet and left the work for the night. On returning in the m ing they found a flowing well, which filled a 2-inch pipe to a heigl 15 feet above the surface. The beds penetrated were as follows

Record of Wykes well, Boyden.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and gravel	20	20
Sand with some water	2	22
Gravel and sand	8	30
Clay and gravel	20	50
Clay	25	75
Gravel with water	5	80
Blue clay	35	115
Sand and gravel with water that overflows	15	130
No record	38	168

The water is hard, with some gas, probably CO_2, and much carbonate of iron is deposited about the well. It flows 6 gallons a minute and has a temperature of 49°. The following partial analysis was made by Dr. A. B. Prescott, of the University of Michigan, November 23, 1897:

Partial analysis of water from Wykes well, Boyden.

	Parts per million.
Total solids	187
Free ammonia	.08
Albuminoid ammonia	.007

Hardness, 140.

It is stated in connection with the analysis that there are light quantities of iron, sulphates, and chlorides, and larger quantities of carbonate.

This water is used commercially, the price for a 4-gallon case, including the packages, being $1.50, delivered at freight or express offices in Mount Pleasant, Mich. The water is also shipped in barrels, at the rate of 5 cents a gallon.

The well is situated on low ground near the Chippewa Valley, and the catchment area is probably on the higher land to the west.

Blanchard.—From a water-supply schedule obtained by W. F. Cooper it is learned that a flowing well was made on the farm of Stephen Pumfrey, 3 miles from Blanchard, in 1895. It was dug to a depth of 30 feet, with a diameter of 3 feet, and discharges about 3 buckets a minute at the well mouth. The water will rise several feet above the surface if confined in a pipe. The water is hard, with some iron. The cost of the well was $50.

There are springs along Pine River in this township which carry an oily scum, which is thought by the residents to indicate the presence of oil, but as the drift in that vicinity is very thick it is improbable that there would be oil issuing from the underlying rocks.

MOUNT PLEASANT WATER SUPPLIES.

Waterworks.—The public water supply of Mount Pleasant was originally obtained from a well 17 feet in diameter to a depth of 20 feet and 6 feet in diameter for 8 feet farther, in the bottom of which four short pipes were driven to the water bed. To this supply has been

added seven 6-inch and 8-inch driven wells located on the river flat. These wells are 24 and 26 feet deep through 7 feet of surface soil, 16 feet of hardpan, and 2 feet of water gravel. The wells at one time flowed, one having sufficient head to flow 8 feet above the surface from an open pipe. The wells are all supplied from the same water beds, as is shown by the fact that pumping one well will lower the water in others 200 feet distant. These wells having failed to furnish a sufficient supply, several cisterns modeled after the original one used at the installation of the waterworks plant have been made, each being in part 25 and in part 6 feet in diameter and having driven wells in the bottom. This arrangement now supplies 750,000 gallons daily, but during a dry summer the supply is low.

Private wells.—The shallow pump wells of private citizens generally give a good supply of water at a depth of 15 to 20 feet in the northern part of the city, while in the southern part there is a marked difference in the shallow wells. Those in the vicinity of the normal school pass into clay under a slight covering of sand. The well drillers have found the change there quite sharp between a belt of gravel and sand bordering the river and the clay which sets in near the normal. None of the wells used to furnish water for domestic supply reach bed rock, all being in the drift, which in the vicinity of Mount Pleasant is about 435 feet thick.

Doctor Getchell, lots 3, 4, and 6 of block 31, has given the following record of a well drilled on his property:

Record of Getchell well, Mount Pleasant.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	30	30
Clay	30	60
Sand and water	5	65
Hardpan	8	73
Some coal pieces in clay	9	82
Sand	5	87
Water in gravel	14	101

This well caused some excitement because of the presence of the drift coal, and other wells 200, 255, and 355 feet in depth were drilled on various lots adjacent to Doctor Getchell's properties, but no rock was found. Later careful drilling by the Midland Chemical Company on their property on section 10, north of the city, on ground about 770 feet above sea level, has shown the rock to be reached at 435 feet below the surface and to have the drift covering shown in the following record:

ht Pleasant city and Midland Chemical Company well, (sec. 10, T. 14 N., R. 4 W.)

[From samples and notes of A. Borden; determinations by A. C. Lane.]

	Thickness.	Total.
	Feet.	*Feet.*
.....	80	80
.....	20	100
.....	20	120
.....	160	280
th water; coarse gravel on top, fine sand below.....	74	354
.....	26	380
ıe till with broken coal measures.....	55	435
th streaks of coal (410, 435, and 560 feet), sandstone, limestone, of iron and fire clay, mostly less than 5 feet thick.....	185	620
d rock with mineral water.....	90	710
rock with a strong flow of water not so salt.....	80	790
imestone.....	30	820
e.....	30	850
ıe (Parma) with very salt water.....	120	970
ıe (Maxville) actively effervescing.....	55	1,025
.....	5	1,030
.....	20	1,050
ihale.....	75	1,125
dolomite.....	100	1,225
rly pure (gypsum).....	45	1,270
), and anhydrite.....	103	1,373
ı of Marshall).....	8	1,381
.....	5	1,386
.....	4	1,390
.....	15	1,405
k, with heavy brine originally 1,463 feet deep, afterwards about ling in red rock.....	180	1,585

basket factory of J. Flynn, according to a statement from ıy L. J. Lincoln, a small flow was found at 150 feet and a of brackish water at 355 feet. The future city supply is to be obtained from deeper wells, as sufficient tests have e to show that the water is not abundant in the lower ıe drift and that it is also too highly mineralized to be y.

VATER SUPPLIES OF CLARE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

ounty, of which Harrison is the county seat, lies imme- ırth of Isabella County, near the center of the southern The northwestern part is traversed by Muskegon River, on rs of which there is a rather barren sandy plain from 5 to n width. The extreme northwest corner has a few square illable land which has been settled and where wells have ined at moderate depths, usually less than 50 feet.

ıst of the Muskegon River sand plain is a prominent system running from the northeast corner of the county ward past Harrison into northwestern Isabella County. ıart of it is unsettled. The few wells indicate that the le generally lies 75 to 100 feet or more below the surface. wood Township, however, there is a settlement in which

wells have been found at 40 to 60 feet, the altitude being low than in the part of the moraine to the east and south.

The southeastern part of the county slopes rapidly down to old lake plain covered by the Glacial Lake Saginaw, and is tr ersed by weak morainic ridges. Flowing wells have been found the valleys and low tracts in this part of the county, which partly discussed in the report by Mr. Gregory (p. 106) and partly the writer herewith.

WATERWORKS.

CLARE.

Clare, with a population of about 1,600, has a waterworks sy supplied by a well about 40 feet in depth. The water is from gr and rises nearly level with the surface. The supply is of good ity and adequate to the needs of the town. Tobacco River is connected with the system and can be utilized in case of fire. ordinary pressure is 20 pounds and the fire pressure 60 pou The wells of this village range in depth from 17 to 42 feet.

FARWELL.

Farwell, with a population of about 500, has a waterworks sy supplied from a pond fed by a spring brook. Water is pu direct, and an ordinary pressure of 40 pounds and a fire pre of 140 pounds furnished. The wells of the town are 20 to 23 in depth and are in common use by the residents.

HARRISON.

The public supply of Harrison, the county seat, is pumped Bud Lake direct to the mains, which have a length of 1½ n Very few private wells are in use.

MISCELLANEOUS TOWN SUPPLIES.

At Temple, which is located on the bank of the Muskegon R wells are driven through sand about 40 feet and obtain an abun supply.

At Clarence the wells vary greatly in depth, there being a r from 16 to 116 feet in the vicinity of the hamlet. The water i deep wells stands about 20 feet below the surface.

At Crooked Lake driven wells and the lake constitute the v supply. The wells are from 25 to 50 feet in depth and have v standing about 12 feet below the surface.

FLOWING WELLS.

SHERIDAN TOWNSHIP.

In the central part of Sheridan Township, the southeast township : Clare County, at an altitude about 800 feet above the sea, is a mall flowing-well district. It is 1 to 2 miles northwest and a little bove the level of the highest shore of the Glacial Lake Saginaw.

Only five wells were noted, but possibly others occur, as the notes vere made some years ago when tracing the shore line through the egion. The strongest flow is at the residence of Joseph Schenck, n the east side of sec. 16, its yield being 5 gallons a minute from 1¼-inch pipe. It is reported to have flowed 12 gallons a minute rom a 2-inch pipe before the reducer was put on. The temperature 47° F. The depth is 103 feet and water will rise to at least 5 feet bove the surface. The well passed through a clayey till for 75 feet nd then through sand to a crust at bottom, beneath which the trong flow was found. The other flows are: George Chunz well, in vest part of sec. 15; schoolhouse well, in northeast part of sec. 15 very weak flow from well 66 feet); John Smith well, in southwest orner sec. 11 (depth 106 feet, altitude 10 to 12 feet above schoolouse well, and stronger flow); George Schunk well, in west side ec. 10 (depth 75 feet, weak flow). The catchment area is likely to e in higher land that lies immediately northwest of these wells.

WATER SUPPLIES OF GLADWIN COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Gladwin County is traversed nearly centrally from southwest to northeast by the shore line which marked the upper limits of the Glacial Lake Saginaw. There is a rapid rise from about 800 feet at the shore line to 1,100 feet or more in the northwest corner of the county. East from the shore line is a gradual descent to Tittabawassee River, followed by a slight rise to a water-laid moraine that lies east of the river.

Flowing wells have been obtained at several places along or near the old lake shore, and there is a possibility of much more extensive development not only in the vicinity of this shore line but in valleys and lowlands between morainic ridges to the west. Flows may perhaps be obtained along Tittabawassee River, but that portion of the county is still largely unsettled.

The catchment areas which supply the flowing wells are to be found, in all probability, in the more elevated country west and north of the wells, as in the neighboring larger flowing-well districts in Isabella County described by Gregory (pp. 92–111), of which this chain of flowing-well *districts may* be regarded as the continuation.

FLOWING WELLS.

GLADWIN DISTRICT.

This includes not only flowing wells in the village, but scattered flows to the south, between Gladwin and Beaverton, and a flow at the county infirmary north of Gladwin. The strip is nearly 10 miles long and lies along or near North Cedar River. The flows in Gladwin and at the infirmary are in the valley, but some of those south are on the bordering lake plain, not far below the old shore.

At the Gladwin waterworks, in the west part of the village, on ground about 15 feet lower than the railroad station, or 765 feet above tide, are two wells which flow with a head about 25 feet above the surface. One well was sunk to a depth of 465 feet, but found a bitter water in the lower part, so that it is shut out and the supply is obtained from 160 to 180 feet, in rock which immediately underlies the drift. The other well was sunk to a depth of only 165 feet. The first well is reported by Gregory to flow about 100 gallons a minute. The river is drawn upon in case of fire, and pumps (Gordon & Maxwell) are installed which have a daily capacity of 1,500,000 gallons.

The flowing well at the infirmary in sec. 25, T. 19, R. 2 W. is only 37 feet deep and has a head of at least 6 feet. It is from glacial deposits.

W. M. Bush, a short distance south of Gladwin, has a flowing well reported to be 230 feet deep and 4 inches in diameter. Gregory learned that its rate of flow is 5 gallons a minute.

About 5 miles south of Gladwin, on the W. H. McCulloch farm, in the east part of sec. 34, T. 18, R. 2 W., is a flowing well 68 feet deep. It stands near the bluff of the North Fork of Tobacco River, about 25 feet above the level of the stream.

In the south part of sec. 36, T. 18, R. 2 W. is a well on the farm of Frank Finsel, which has a head level with the surface. It stands near the beach of Lake Saginaw at an altitude very nearly 800 feet above tide. The depth is 135 feet, and the well is entirely through clay to the water-bearing gravel at bottom.

Fraser and Button, of Gladwin, made in 1902 a flowing well 400 feet in depth and 4 inches in diameter. The water is running to waste in large quantities.[a]

On the farm of A. Adams, 6 miles south of Gladwin, in sec. 36, a well 44 feet in depth and 2 inches in diameter was made in 1902 at a cost of $50. It flows 25 gallons a minute. The water is reported to be hard.[a]

McCLURE DISTRICT.

On the plain west of Sugar River, north of McClure post-office, several flowing wells have been obtained at moderate depths, none being more than 100 feet. Six of the wells are on the Jacob Schwartz farm

[a] Data collected by W. F. Cooper.

d one on the Dutscher farm. The altitude is about 810 feet or but ghtly higher than the beach of Lake Saginaw, which comes to Sugar ver south of McClure. This plain, however, is back of a moraine uich, to the southwest, lies near the shore of the old lake. The tchment area is probably in the country which rises west or northst from the wells. No data were obtained as to the strength of ese wells further than the statement that they all had "good flows."

EDWARDS DISTRICT.

About a mile south of Edwards post-office, in the northern edge of ie northeast township of Gladwin County, is a small group of shallow owing wells 30 to 35 feet deep. They are in secs. 5, 8, and 9, T. 20, . 2 E., on a plain of black, sandy loam, between the middle and east ranch of Tittabawassee River, standing about 800 feet above tide. here is a slight depression where the wells are located, perhaps 10 et below bordering tracts. The catchment area seems likely to be ithin a mile or two north, on sandy ground, near Edwards post-office, or the shallowness of the wells and the slight head which they show scarcely 5 feet) seems consistent with a near, rather than a remote, atchment area. The wells appear to have passed through a few feet f clayey material under the sandy loam before striking water. The llowing were the wells in operation at the time of observation in 1901: ra Mayes, east part sec. 5, depth about 30 feet; Ed. Hayes, north art sec. 8, depth about 30 feet; Lewis Harrell, northwest corner ec. 8, depth 33 feet; and Henry De Lord, west part sec. 9, depth bout 35 feet.

WATER SUPPLIES OF BAY COUNTY.

By W. F. Cooper.

FLOWING WELLS.

The artesian area of Bay County (Pl. III) is in the lowlands lying vest of Saginaw Bay and in the valley of the two forks of Kawkawlin River, though there are other small tracts on higher land. The reater part of the artesian water is from the drift.

WILLIAMS TOWNSHIP.

In the northeastern part of Williams Township (T. 14, R. 3 E.) the lepth of flowing wells ranges from 80 to 95 feet, the wells being found n secs. 1, 2, 3, 4, 11, 12, and 13. The water is slightly salty and comes rom gravel beds in the drift. This area formerly extended farther ast into Monitor Township (T. 14 N., R. 4 E.), where flows were obtained in the valley of Culver Creek in secs. 7, 17, 18, 19, and 20. Quite recently Mr. Theodore Archambeau while drilling for coal in the

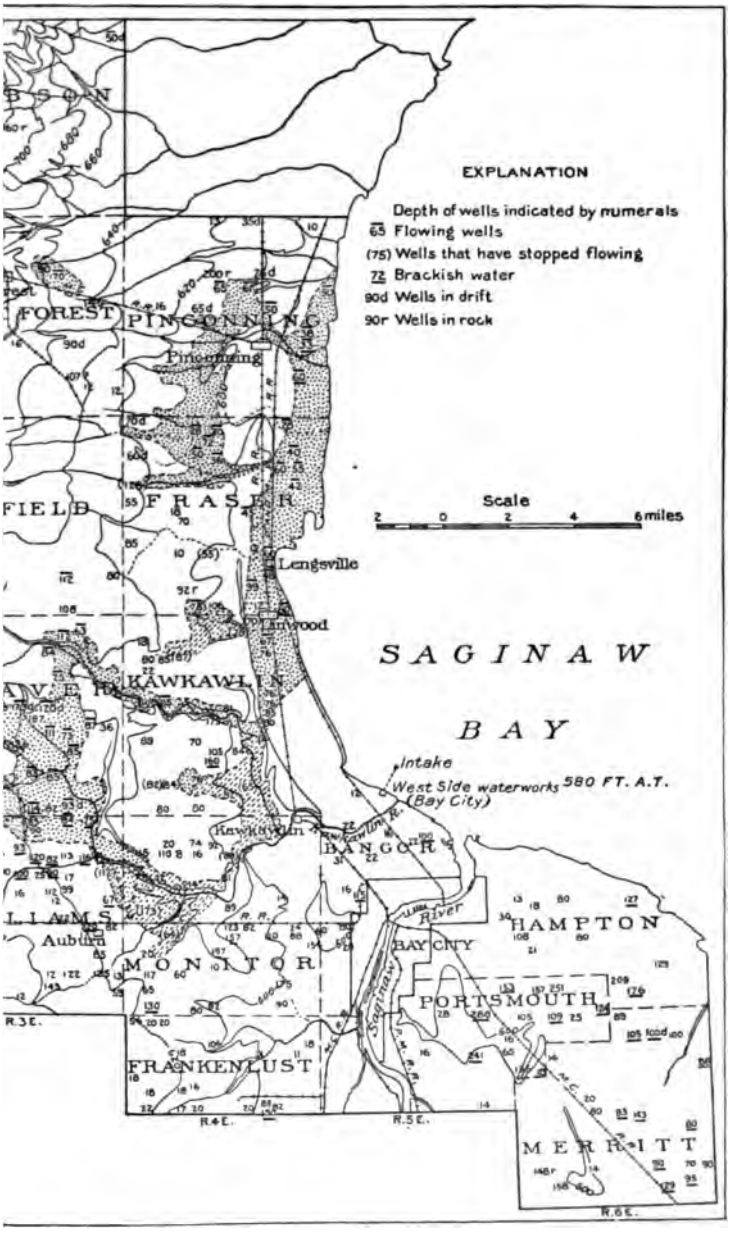
valley of the south fork of Kawkawlin River obtained a flow near the north line of sec. 10, T. 14 N., R. 4 E., which seems to be a northerly continuation of the former Culver Creek area.

Numerous wells in the eastern half of Williams Township obtain their supply from the drift down to a depth of 220 feet, as in the deep well at Auburn, which penetrated first 80 feet of clay, then 138 feet of sand and 2 feet of gravel, the latter resting on the shale rock of the coal measures. The gravel is water bearing, but the overlying sand, although allowing the water to permeate it, will not furnish it in sufficient quantities for an adequate or stable supply. The drift-filled pre-Glacial drainage valley over which Auburn stands trends east to west and increases in depth westward. Along its course it would be well wherever possible to obtain water at a depth of less than 80 feet. The process of drilling through sand is difficult and expensive, besides added to the difficulty of keeping the casing free from clogging.

KAWKAWLIN VALLEY.

Northward from Williams, in Beaver Township (T. 15 N., R. 3 E.), the area of artesian water is in a general way contiguous to the basin of the two forks of Kawkawlin River, and to a drift-filled pre-Glacial channel which has a southwesterly course across Beaver Township, as indicated on the map. Beds of gravel, apparently of inter-Glacia age, deposited in the coal measures, within the limits of this old channel, furnish the conditions necessary for flows. The source o water is probably from the north and the west. Where such bed are tapped in this relatively depressed area, flowing wells are obtained There are at least two and probably three water horizons in Beave Township—the uppermost at a depth of 60 to 80 feet, a lower one a 110 feet, and a still deeper one at 173 to 197 feet. Some wells obtai flows both at 65 and 110 feet. The amount of flow does not see to bear any relation to the depth. Two of the heaviest of the flowi wells have depths as widely different as 93 and 173 feet, one in t SW. ¼ sec. 35 being 93 feet and the Cherry well in the SE. ¼ sec. 1 Beaver Township, being 173 feet.

In Kawkawlin Township (T. 15 N., R. 4 E.) artesian waters ha been obtained in rather limited areas adjacent to north fork of Ka kawlin River in the northeastern and southwestern portions of t township. This latter area formerly opened out to the south include the lower reaches of the north fork down to its junction wi the south fork in Monitor Township. The very limited area at t northeast corner of sec. 31 is in a swale (traversed by drain No. The depth here is 82 feet to water, which comes from a gravel depo overlying the rock. An artesian well from the rock is found in N ¼ sec. 21, the depth being 175 feet.



TOPOGRAPHIC AND ARTESIAN-WELL MAP OF BAY COUNTY.

FRASER FIELD.

In Fraser Township the artesian conditions appear comparatively simple, flows being obtained in gravel-bearing beds probably just overlying the rock, in a plain whose catchment area is on higher land to the northwest. The wells are restricted to the area adjacent to Saginaw Bay, a portion of the valley of Mitchie Creek, and the valley adjacent to the Chute Creek drainage in the western half of Fraser Township. The depth varies from 28 or 30 feet in the northern portion of the township to as much as 75 feet along the road west from Kinwood, and follows very nearly the inequalities of the rock elevation. A subordinate area formerly extended a short distance up the swale now traversed by the Ryan drain at the line of secs. 21 and 28, 22 and 27. In the NW. ¼ sec. 18 is a well to bed rock, 128 feet deep, which has ceased flowing.

PINCONNING FIELD.

In Pinconning Township the Chute Creek area of artesian water is extended northward through the central part of the township, flows being obtained from depths ranging from 45 to 85 feet. Apparently the water is obtained from gravel beds overlying the rock, in a similar position to those southward. East of the Algonquin beach, along the State road, flows have occasionally been tapped at depths ranging from 38 to 60 feet. Detailed data regarding wells at Pinconning, collected by W. M. Gregory, are given on pp. 270–271.

MOUNT FOREST FIELD.

A small area of artesian water has been found in Mount Forest Township, which with further drilling may be considerably extended. The flows are obtained in the SE. ¼ sec. 10, where coal drilling was carried on for John Mansfield. There are flows at 90 feet (at the base of the drift), and in beds of sand rock in the coal measures. Prospectively the best area to test further would be to the north and west in the basin of Saganing Creek.

SUMMARY.

Taking the artesian waters as a whole almost all the flows are obtained from gravel beds, either at the base of the drift formation or interbedded with Glacial clays. Artesian water is also often obtained in relatively depressed areas in the line of pre-Glacial valleys. While it is not possible to determine precisely the origin of the flows in the central and northern part of the county, it seems probable that the elevated moraine, covered with sand and gravel, traversing the western portion of Gibson Township in a southwesterly direction, and thence running southerly through Gladwin and Midland counties, furnishes the catchment area. It is also thought that these beds

of sand and gravel which hold the artesian water are inter-Glacial and were covered by beds of clay and hardpan deposited during a later ice advance.

The absence of flowing wells from the drift in the southeastern part of Kawkawlin and the northwestern part of Bangor townships, adjacent to the shore of Saginaw Bay, seems due to the upward rise of bed rock in that direction, and to the almost entire absence there of gravel beds in the drift. The artesian water seems to come from the northwest and to be thus ponded back by the bed rock.

No precise data were obtained concerning the actual amount of water running from the wells nor of the capacity of the nonflowing wells. Shallow wells show a tendency to become lowered in summer, and in some cases fail entirely. The flowing wells are on the whole diminishing slightly in flow and in area, which makes it seem important to keep the water shut off when not in use. The following record sets forth observations which are at hand:

Flowing wells in Bay County.

Township.	Section.	When made.	Remarks.
Beaver	16	1880	Cherry well; depth, 173 feet; no diminution; probably strongest flow in county.
Do	32	.....	William People's well; depth, 74 feet; ceased flowing.
Fraser	2	1898	Depth, 28 feet; continued steady flow, 1900.
Do	6	.....	Great decrease.
Do	28	.....	Flowed in 1892; now ceased.
Kawkawlin	3	1871	Stopped flowing in 1884; now 4 feet below surface.
Do	34	1875	Original head, −2 feet; now much lower.
Do	8	1878	Flowed for 3 years; now −8 feet.
Do	19	1884	Flowed in 1900.
Do	34	.....	−2 feet in 1892; −6 feet in 1900.
Do	5	1894	Flowed 1 year; −9 feet in 1904.
Do	31	1894	Flowed 2½ feet above surface; now 1 foot above; weak.
Do	27	1895	Original head +1 foot; in 1900, −6 feet.
Do	32	.....	Flowed ½-inch stream 1½ feet above surface in 1896; ceased in 1900.
Do	32	1896	Original head −6 feet; now much lower.
Do	23	1897	Flowed 1½ feet above surface; ceased in 1900.
Do	34	1897	Flowed 1 foot above surface; 3½ feet below in 1900.
Williams	4	1887	Pioneer well; continued constant in 1900.

The first shaft of the Pittsburg Coal Company, near Amelith, struck a bed of water-bearing sand at a depth of about 40 feet. The great quantity which was pumped out at that time affected the water supply more than 2 miles away, as, for instance, in the case of the well at the Michigan House, which went dry.

NONFLOWING WELLS.

In Merritt and Portsmouth townships shallow surface wells having depths of from 15 to 20 feet often contain an insufficient amount of water, beside being otherwise objectionable on account of surface drainage and organic matters, while brackish water sets in at a depth of about 80 feet, thus leaving but a narrow zone from which water of good quality can be obtained.

In Hampton Township fresh water is obtained at depths ranging from 30 to 80 feet.

In Frankenlust Township fresh water may be obtained down to depths of at least 85 feet, and in general a fairly abundant water supply may be obtained at a depth of less than 50 feet.

In Bangor Township an abundant water supply of good quality is generally obtained at a depth of less than 30 feet, and fresh water is often found to a depth of 80 feet, but brackish water sets in at a little over 100 feet.

In Monitor Township there is no difficulty in obtaining water at depths of less than 90 feet, below which depth it is liable to be brackish.

In Williams Township troublesome sand deposits make deep drilling sometimes necessary; but the western portion of the township usually affords good supplies at moderate depths.

In Beaver and Kawkawlin townships, outside the areas of flowing wells already described, a sufficient supply of water is generally obtainable at a depth of less than 90 feet, though one well in the southwestern part of Beaver went down to 130 feet. Mr. Shaw, in sec. 28, Kawkawlin Township, found fresh water at 105 feet and also in the rock, but at a depth of 160 feet encountered brackish water.

In Fraser and Garfield townships, outside the area of the flowing wells of the Fraser field, fresh water supplies are obtained down to 112 feet, as at Crump post-office. However, in the southwestern portion of Fraser Township several wells 80 or 90 feet have become dry. This may be due to subsurface drainage, though the cause for failure is still an open question. It is probable supplies may be obtained by deepening the wells into the underlying bed rock, say to a depth of about 125 feet. Wells in the western part of Garfield Township are generally shallow and the water is of a quality that suggests a need for deepening to better supplies.

Wells in Pinconning Township usually obtain a sufficient supply at depths of less than 80 feet, but are occasionally much deeper. In the SE. ¼ sec. 9 a well 200 feet deep obtained a good supply of water without objectionable mineral properties.

In Mount Forest Township the wells are generally shallow, except in the southeastern portion, where a few have a depth of 90 to 145 feet, one deep one being at the schoolhouse in sec. 13. These deep wells seem to be free from any objectionable mineral matter.

In Gibson Township most of the wells are shallow, and many should be deepened to insure a permanent and pure supply. In the morainal region in the western part of the township wells have in some cases failed to reach a good supply at 100 feet. At Bentley, however, Mr. William Hinman obtained an abundant amount of good water in a sandstone of the coal measures at a depth of 160 feet.

In order to obtain a permanent supply in the morainal region in the western third of this township it may be necessary to go to a depth similar to that at the Hinman well.

QUALITY OF WATER.

The records of several wells east of Saginaw River in Hampton township show that water containing brine percolates upward in the coal measures to within about 125 feet of the surface, above which fresh water has been obtained at depths ranging from 30 to 80 feet.

A number of well records in Merritt and Portsmouth townships indicate that wells in the drift having a depth of 80 feet generally contain a small amount of saline matter.

A well in sec. 14, Frankenlust Township, obtained fresh water at a depth of 85 feet, but upon being extended to a depth of 135 feet became saline. For the central part of Frankenlust Township the upper limit of saline water is a depth of about 100 feet.

In Bangor Township the upper limit of the percolation of brines is not far from that in Frankenlust Township, while westward in Monitor Township the depth to brines is about the same as in Hampton Township, 125 feet, although wells in the drift are occasionally slightly brackish at about 90 feet.

WATER TEMPERATURES.

The following observations were taken with a standard thermometer, Green No. 7529:

Temperatures of Bay County waters.

	°F.
Shaft of Whatcheer mine, sec. 30, T. 13 N., R. 6 E. at 139 feet	54.5
Same shaft at 155 and 198 feet	54
Shaft 1½ miles east of Auburn, water pumped in large volume from a depth of 90 feet (tested also by Dr. A. C. Lane)	50
Flowing well near southwest corner sec. 27, Pinconning Township (Lane)	51.5
Rich's bakery well at Pinconning, August 6, 1901 (Lane)	48.5
Saginaw Bay:	
Average of 84 observations, September 12 to 26, 1904, between 5.30 a. m. and 7 p. m.	72.11
Highest temperature, September 12 to 26, at 3 p. m.; seven observations	75.11
Night observations between 9 p. m. and 3 a. m., September 22 to 23 and September 25–26; eight observations, average	66.54
Lowest temperatures noted were at 3 a. m; average	65.25
Bay City, wells 80 feet deep (tested by Lane)	50

TOWN SUPPLIES.

BAY CITY AND WEST BAY CITY.

Bay City and West Bay City (now one corporation) obtain publi supplies from Saginaw Bay, there being two pumping stations, on taking water near shore, the other 3 miles out. The water is not u

to the standard desired, owing to the shallowness of the bay and consequent turbidity during storms, and to the dangers of contamination when an off-shore breeze carries the sewage into the bay. The present supply may be rendered more satisfactory by a further extension into the bay and fuller protection from contamination. As to other sources of water supply, it may be stated that it will be feasible to take water from wells in the Marshall sandstone in Huron County, where large quantities of fresh water are found, though perhaps this source would need to be restricted to supplies for drinking, leaving the factories, lawns, and fire protection to be supplied from the bay water. It will also be feasible to pipe water from the headwaters of Tittabawassee River, a scheme suggested by Superintendent Dunbar of the Bay City waterworks. There does not appear to be an adequate supply of fresh water obtainable either from the glacial deposits or the rock in wells within the limits of the city or on its immediate borders.

SAGINAW BAY DRAINAGE BASIN SOUTH OF BAY AND ISABELLA COUNTIES.

By Charles A. Davis.

INTRODUCTION.

LOCATION AND BOUNDARIES.

The district covered by this report forms a considerable part of one of the physiographic units which make up the Southern Peninsula—namely, the drainage basin of Saginaw Bay. It includes Midland County and counties lying south of Isabella and Bay counties. The natural boundaries of this area are, in general, moraines left by the Saginaw lobe of the last ice sheet as it melted back into Saginaw Bay. From an inspection of the map of the State showing the streams it is seen that the district under discussion includes the western part of Sanilac County, all of Tuscola, all of Lapeer except a small part of the eastern side, the northern half of Oakland, the northern half of Livingston, the northeast half of Shiawassee, all of Genesee and Saginaw, and the larger part of Gratiot County.

PHYSIOGRAPHIC FEATURES.

A brief account of the physiographic features of this region will make plain its peculiarities of water supply, and especially the infrequency of flowing-well areas in some parts and relative frequency in others.

There is a close relation between the development of the flowing-well areas and the physical features of the region.

The borders of the greater part of the district are rather rough and hilly, with more or less well-defined, but frequently ill-drained, valleys.

In other words, the bordering divide of the district is made up of a series of well-marked ridges of glacial origin, with valleys which represent either times of rapid melting, channels which originally carried off the water from the front of the melting ice, or, more rarely, preexisting valleys which were occupied by ice masses that persisted until masses around them melted.

The width of this hilly area is greatest in the southern and eastern parts of the district, where also the hills are more prominent and the valleys broader. It is very narrow and the ridges scarcely noticeable in the region extending from Owosso, in Shiawassee County, northeasterly into Gratiot County, where the divides between the headwaters of the streams running into Lake Huron through Saginaw Bay and those tributary to Lake Michigan are so flat in places as to be occupied by swamps.

Passing from any part of this outer rim of the drainage basin of Saginaw Bay toward the bay one usually traverses a number of ridges of successively lower height, with intervals of gently sloping plain, upon which are more or less extensive and continuous lines of low sand ridges. The plain is slightly undulating in places, but in the main gives a definite impression of being very flat and featureless. In it the valleys of the streams are narrow and shallow, with steep sides, and the streams themselves are generally sluggish and their waters muddy. Much of this basin is an old lake bottom covered by the waters from the melting ice impounded between the front of the ice and the bordering rim of the basin at the level of the lowest point on the rim that could serve as an outlet.

The sandy ridges which occur upon it are shore lines, marking various stages or halts, longer or shorter, in the subsidence of the temporary body of water. There are, therefore, two distinct types of territory covered by this investigation, the hill and valley type and the flat or slightly undulating plain.

Theoretical considerations would provide for flowing wells oftener in hilly districts than in plains, because conditions under which flows occur are more common in this type of country. Such, however, does not seem to be the case in the area under discussion, for the larger flowing-well areas and the larger number of wells exist in the plain and not always, by any means, in the vicinity of the ridges.

This is, however, due to several easily determined reasons, not the least of which is purely accidental and in no way connected with causes which do or do not produce flowing wells. Flowing wells are better developed on the plains than in rolling districts, for the simple reason that the farm buildings in the rolling districts are generally placed on the higher land, often on the tops of the hills, unless the valleys are very broad and well drained, and in this general location the wells are above the level to which artesian water will rise. Farmers often seem

ıindful of the fact that the water table is farther from the surface he top of an elevation than it is on the bordering lower ground if water-bearing material is of the same character throughout the ;e.

f the water is in a bed of coarse material, such as sand or gravel, this lies between much less permeable beds or deposits, all running n the top of a hill to the bottom, the water at the top of the eleva- ı will have less tendency to rise in the well than it will halfway ;n the slope or at the bottom.

Moreover, the supply will be much more easily exhausted in a well r the top than near the bottom of the slope or in the valley bottom, it is to the valley that the water of the entire bed is passing. In ; there is pressure enough to create artesian or flow conditions the d is greatest at the valley bottom, and there, if anywhere, flows be obtained. Thus the location of farm buildings on the high ds tends to discourage the exploration of lower ground for water, l many places in which good flows might in all probability be ıred remain untested, while the owners of the land pump all the ;er which they use from considerable depths.

n the lake plain, on the other hand, the building sites are not usu- ' elevated much above the general level, and, if flowing wells are nd at all, the area is frequently fully explored and thoroughly 'eloped.

Aside from the above considerations, the different origin of the sur- e deposits in the two districts must be taken into account. In the ged district the coarse and fine materials are interbedded about as 'y were deposited by the melting of the ice which brought them to ; place where they occur and are either entirely unsorted or incom- tely sorted, with coarse rock fragments usually present in great undance. As a consequence, water can find its way into the soil ıdily, and usually, also, into beds of sand or gravel, in which it may stored and from which it is given up readily to wells. In the lake ıin, which was developed under water, the surface deposits have en thoroughly sorted, the coarse material usually being left in the ttoms of the valleys draining into the plain and the finer sands or ıys being carried to the lower-lying parts of the plain, where there ıs deep still water. Such materials are slow to take up water and ry slow to give it up, and, in general, in this region there are few arse beds near the surface to receive the water. Those which do occur ;m generally thin and of small extent, so that the water is easily hausted. Hence the average well is deeper and the water-bearing ds are more fully explored in the plain than in the ridged districts, ıd if flows can be had the fact is more likely to be known and the area lly developed.

The head of flowing wells is likely to be less in the plain than in the ridged areas, since the differences in surface level are generally slight, and unless it is assumed that the beds containing the water are widespread and continuous for long distances (many miles in some cases) the head must be derived from the slight elevations or slopes which do occur, but which, because of the friction, can not give much pressure. Even here, also, the head is strongest at the bottoms of depressions, and frequently it is in valleys alone that flows can be obtained.

WELLS.

TYPES OF WELLS.

In each of these types of country several kinds of wells are in use, but certain types may be considered fairly characteristic of each. In the ridged districts dug and walled wells of the basin type are most common. This is due to the ease with which water is found near the surface, to the abundance of stone for walling up the basin, and to the difficulty which often arises in getting enough water from the bored or tubular wells. Wells of the bored type are usually difficult to put down in these districts, because of the bowlders present in the soil. Drilling and driving are frequently hindered by the same cause. Since dug wells with open basins are always more in danger of contamination from surface drainage, those with iron tubes are coming into use. These are to be preferred, and when a well has been dug down to a good strong supply of water it is possible to convert it from a dug well into a tubular one, which will furnish plenty of water by inserting the proper length of pipe, with or without a strainer, and filling in around it, first, with clean cobble stones or coarse gravel for 3 feet or more, then with finer gravel, which should be carefully tamped down, and then with sand, ending with a few loads of clay at the top. Such a well does not need curbing and is generally guarded against contamination if the work is properly done and clean materials are used in filling in around the tube. Other types are the cemented well, the drain-tiled well, the timbered well (which is especially bad and probably now not common), and the bored, driven, or drilled wells. Flowing wells are usually of the tubular construction. In the plain the most frequent type is the tubular well. Apparently, this is due to the facts that permanent supplies of water are not found near the surface and that in many cases tubular wells are easily put down by boring. Along sand ridges and in other sandy areas in and bordering on the lake plain shallow dug wells are in general use and constitute an important source of supply for farm and house use.

Rock wells also are more frequent in the plain than they are among the ridges, largely because of the greater depth of rock in the latter region, but also because of difficulty with which water is obtained above the rock surface in parts of the plain.

y a small proportion of the wells in the regions here discussed
ly flow, and in areas where flows are known to occur the num-
wells requiring pumps is often larger than the number of flow-
ells. This is due to several causes, among which are the follow-
1) The occurrence of good supplies of water above the water
from which flows come. (2) Location of the mouth of the well
the level to which water will rise. (3) Irregularities in per-
lity and thickness of the water beds from which the flows come,
it water is not yielded with equal readiness from all parts of
(4) Local development of "hardpan" or impermeable cap-
stratum, so that flows are to be had only locally. (5) Driving
pe beyond and casing off the water by the driller through care-
ss. This latter may be due to accident or to wilful cheating by
nest drillers. (6) The shutting off of the flow by raising the cas-
high that water will not run from it. This is sometimes done
ape the necessity of disposing of the waste water. (7) The
r cost of shallow wells compared with deep ones, and some
tainty of getting a flow tends to restrain residents from trying
them.

wing wells occur in 129 districts, distributed as follows: Oak-
County, northwestern part, 4; Lapeer County, including those
sed by Leverett, 9 (2 from rock); Genesee County, 15; Living-
County, 5; Shiawassee County, 5; Gratiot County, 21 (rock flows
t of 2 of these); Midland County, 7 (including rock flows);
aw County, 12 (not including rock flows); Tuscola County,
from drift).

this list flows from rock are of small consequence except in
la County, and about one-half the number in Tuscola County
ift flows, many of which are within areas of flowing wells from
d rock. Saginaw County would have a larger number if the
of flows from bed rock were included in this list.

UTILIZATION OF FLOWING WELLS.

ften seems that there is too little appreciation of the possibilities
wing wells, for, beyond the rather frequent use of the waste for
g in dairies or milk houses and its rather rare use for irrigating
ns or grass plots, little utilization is made of the great volumes
ter which many flowing wells pour out. Some additional uses
occur to the writer are the following: (1) Its more frequent
irrigate lawns and gardens. This could often be arranged by
ing a hose to the outlet of the well or by dividing the flow by
e of underground pipes, as is occasionally done to conduct the
of a well to some distant building. (2) As source of supply
h and ice ponds. Near Midland and at a few other points such
have been constructed and not only pay the owners largely for

the investment but add materially to the beauty of their farms. The ponds are simple in construction and are apparently not expensive to build. Carp and other fish flourish in them, and the ice from them is of much greater purity than that from rivers. (3) To fill reservoirs. Most farms, where there are flowing wells, are without any protection against fire except the small amount furnished by the water held in the tanks at the wells. A large cistern or even an old dug well could be kept full all the time by turning the waste water through it. (4) By the use of a water motor, where the head is sufficient, the water could be automatically pumped from the well to the house or barn of the owner and then stored in tanks and all of the benefits of a waterworks system be enjoyed in both places, provided the tanks were placed high enough to give pressure. (5) By the use of a hydraulic ram, which is less expensive than a motor and very efficient, even with a very small flow and slight head (2 feet or more), the pumping could be done more cheaply and the water of flows at a considerable distance could be forced to the buildings. This means of pumping seems to have been entirely overlooked by the farmers throughout the region visited, and if used, would solve many problems relating to water supply.

LOSS OF HEAD.

Loss of head in flowing wells in the region may be due to overdevelopment in a given basin, either by sinking too many wells or by unwise distribution of wells, or by allowing wells to flow freely; leaks caused by splitting the casing in driving (a defect that is in some cases not apparent for some time); leaks caused by rusting of the casing; water rising around the casing because of imperfect driving; fine sand filling the bottom of the casing; filling at the bottom, by caving from the sides where the casing is incomplete; obstructions put in at the top of the casing; clogging of the strainer on the point; drought in the catchment area; excessive draining of the surface of the catchment area; or subsurface drainage.

OVERDEVELOPMENT.

This consists of putting down wells until the continued outflow is greater than the amount of water which flows into the water-bearing strata from all sources, and the loss of head which invariably follows is directly due to useless waste in most cases. In a considerable number of places it was reported that there had been a gradual loss of head or that some wells had ceased to flow, as the area had been fully developed. In many cases it was said that wells had ceased flowing when others were put down on lower ground near by.

There is no absolute remedy for this, but it is evident that a reasonable use and conservation of the supply of a given area will allow

ıy more to use the supply and prolong the period of use. The est and cheapest method of conserving the supply is to reduce the of the outflow pipes to such a diameter that the owner's needs satisfied without great waste. The use of cocks or valves is to be ›mmended in some cases where there is no danger of the well silt- up. Wooden plugs with small holes bored through them are ctive and very quickly and cheaply provided. The need of intelli- t means of checking overdevelopment and waste was observed in rly every part of the region covered by this investigation. At ıa there was considerable discussion regarding the advisability of ıring legislation to prevent further deterioration of the supply. St. Louis the flowing wells of most private owners were stopped by public wells, but after these were abandoned they were not prop- plugged, and some at least are still flowing and keep the head manently low.

LEAKS CAUSED BY SPLITTING THE CASING.

'he splitting happens when the casing is being driven, but the ılts are not apparent for some time after this, because it takes e for the water to make a passage for itself through the ground, ıer to the surface, or to some stratum into which it can flow. The y remedy is to pull the casing out and replace the split pipe with a section.

LEAKS CAUSED BY RUSTING OF CASING.

These leaks occur in wells which have been down a long time, espe- lly where 1-inch or 1¼-inch black pipe was used for casing. The ks frequently occur so near the surface that the water finds its way around the casing and makes the trouble known. The use of vanized pipe and of large-sized pipe with thick walls will prob- y prevent this sort of trouble for a very long time. The drift ters contain so much dissolved carbon dioxide that they have a rked corrosive effect upon unprotected iron.

IMPERFECT DRIVING.

This is a frequent cause of the loss of head in shallow wells of the ed or driven type. The pipe is not driven straight, and in trying get it right the strata above the water becomes sufficiently dis- bed for the water to find a way to the surface and thus less goes ough the casing. This condition may sometimes be remedied by ıping clay, then cement, around the pipe where it comes from the ınd. The clay alone will sometimes be sufficient, if a considerable ckness is used. In case the leak is a very large one some heavier terial like cobble stones may be used first, and the clay put over em.

FINE SAND AND SILT.

In some areas trouble with fine sand was reported, as at Ortonville, where the sand was so fine that a sand screen could not be used. In several areas where the water-bearing strata were coarse, there was often enough fine material in them to fill up gradually the lower part of the casing or the point when this was present. Sand pumping is the usual remedy for this trouble, and was reported as fairly cheap and satisfactory.

CAVING IN AT THE SIDES.

In the Ortonville and Davison areas, and in other districts where the clays over the water-bearing beds are sufficiently compact, many of the holes are not cased beyond a single length of the pipe. Such holes sometimes break down at the sides, the débris stopping or reducing the flow. Such accidents may be repaired by reaming out the hole, but usually a new well is sunk.

OBSTRUCTIONS PUT IN AT THE TOP OF THE CASING.

A few cases came to notice where children had put pebbles and other obstructions in the pipe where flows were small, with the result that they were still further reduced or entirely stopped.

CLOGGING OF THE STRAINER ON THE POINT.

This is a subject to which the writer has given particular attention. The clogging is found to happen in three ways: (*a*) By the gradual accumulation of fine silt or sand in the meshes of the strainer and in the point itself, so that the water can no longer find its way into the pipe. (*b*) By the breaking of the screen during driving and subsequent filling of the point with sand or silt. (*c*) By the incrustation of the strainer by chemical precipitation.

Character of incrustation.—Of these, the first two can usually be remedied by sand pumping. The third is of such importance that it needs further investigation, but deserves notice here, in order that attention of other observers may be called to it. The "point" of the well tube is a section of galvanized-iron pipe, from 2 to 4 feet in length, and of the same diameter as the casing of the wall, in which holes a fourth of an inch or more in diameter are bored at frequent intervals. The lower end is provided with a solid conical point, the upper with a thread, all except the point is covered with brass-wire gauze, having 60 meshes per linear inch for ordinary sands and gravel and 80 or 100 meshes for finer quicksands. Outside this gauze jacket is a protecting sheet of perforated brass to keep the gauze from injury while being driven. It was found on inquiry among well drillers that in some tubular wells in the drift, both flowing wells and pump wells, in which these points were used, the strainers become "corroded"

er a longer or shorter time, varying even in the same locality, and water was to be had. Inquiry as to the nature of the corrosion led to bring forth any satisfactory description of it or of the appearce of the strainer after it was corroded, but all agreed that the only nedy was to pull the pipe out and take the old strainer off and place it with a new one. Efforts to secure one of the corroded ints were finally successful through the kindness of Mr. H. Chivers, Alma, a driller of much experience in putting down tubular wells the drift, who furnished a "corroded" point from a pump well 62 t deep, which had been in use four or five years, and in which the ter stood at about 12 feet below the surface. In this well the ter came from fine gravel mixed with sand. It took but a glance establish the fact that the point was not corroded, but incrusted a dense coating of mineral matter which not only had filled up the shes of the fine wire gauze but also had covered the outer protect- sheet. This coating was firm, hard though easily scratched with nife, compact, of a bluish or grayish-white color, and in some places millimeters or more thick but not uniformly spread over the entire rface. It was so firmly attached to the metal that it generally isted the severe scraping which it received while being pulled from e ground, and was not easily scaled off, even when dry. Upon the ver part of the strainer, where the incrustation was thickest, large mbers of sand grains and small pebbles were cemented to the surce. Upon the upper part of the strainer the coating, while thinner d rather fragile, was still effective in closing the meshes of the screen. some places it was brownish red (from the presence of iron), and in hers dark bluish gray.

Composition of incrustation.—A qualitative analysis of the incrustg material showed that it was principally calcium carbonate mixed th fine silt and containing iron in small quantities. It dissolved ry readily in acids with effervescence, and it is probable that crusted points could be quickly freed from the coating by painting th dilute muriatic acid. It might also be feasible to devise some y of dissolving this coating off without drawing the pipe out of the ound, since the solubility is so great.

The incrustation was noticeably heavier at the bottom of the rainer than it was above, and even extended down on the cone at the d. This greater thickness may be due to the fact that only that rt of the point and strainer penetrated the water-bearing stratum d that only that part which was in water was heavily coated.

Manner of coating.—A study of the wire gauze under a hand lens ade it apparent that the deposit was at first laid on around the wires d as it increased in thickness the openings of the mesh were filled d the deposit thus formed was then coated over by later deposition. is evident that with a 100-mesh (linear to an inch) screen the

deposit upon the wires has only to be one two-hundredth of an inch in thickness to practically close the opening.

Cause of the deposit.—The deposition was due to some chemical action, which apparently released the calcium carbonate from solution or decomposed the bicarbonate of calcium, probably the latter, freeing the carbonic acid and precipitating the calcium as monocarbonate upon the metal. This would be natural if the metal showed any effects of the action of the acid upon it, but none could be discovered in the material at hand. The suggestion also was made that there was a feeble electrolytic action set up by the contact of the brass and the zinc coating to the iron pipe, or to the iron itself, and this is somewhat the more worthy of investigation, since there is on the market the Walker sand screen for large-sized tubular wells, which is entirely constructed of brass and which is reported to keep entirely free from incrustation, even in water where the brass and iron screens soon coat over and stop the inflow.

Importance of incrustation.—In the course of the season's work it became apparent that in a region where the drift is an important source of water supply, incrustation may become a very important cause of the diminution or entire loss of water. In single cases the cost of repairing and restoring a well is not great, but in the aggregate the loss to the persons depending upon tubular wells, in both money and time consumed, must be very great. Moreover, towns depending on this type of wells for their public supply may find it failing and attribute this to some irreparable cause and abandon the wells entirely or go to the expense of putting down new ones when this cause is alone responsible. At St. Louis, Mich., the wells were abandoned when they began to fail, and the water now in use is pumped from Pine River. At Holly a new set of wells was being drilled, in part at least, because the old ones were so nearly stopped up. At Ann Arbor the tubes of some of the wells have been pulled out and the strainers removed and others abandoned. At Owosso several of the wells of the city waterworks were reported to be out of commission for no known reason unless from this cause. They had ceased to yield water and had been abandoned. These instances might be multiplied, but it is evident that the whole matter of the formation of such deposits needs careful study.

DROUGHT IN THE CATCHMENT AREA.

This is a very effective cause of failure in districts where the development of wells of a given area is so great that the amount of water used by them is nearly equal to the amount sent into the water-bearing stratum from the catchment area. A slight decrease in the rainfall affects the supply of the whole area very quickly, the head being lowered so that the wells may cease flowing entirely, either for a long

riod, where there is a prolonged drought, or simply during the dry ason of the year. In Midland County a number of wells were orted to stop flowing each summer, unless the season was a very wet e. In Genesee County, near Flint, was a well which showed marked ctuations in level according to the rainfall. Many other cases ght be cited.

SURFACE DRAINAGE IN THE CATCHMENT AREA.

The effects of surface drainage are certain to make themselves felt the near future, if they have not done so already. The last few ars has witnessed an immense amount of ditching to carry off the rface waters and of drain laying to remove quickly the subsurface ters which may interfere with certain crops. The effect is to so idly carry off the water of rain and snowfall to the rivers that, cept in very sandy soils, but little gets into the ground. As a sult the ground-water level must be gradually lowered. In fact, it is eady much lower than it was before ditching began, and, as is inted out in several places in this report, has been the primary cause the extensive use of deep wells to reach supplies far below the surce in areas where formerly abundant water was to be found near the rface. If the ditching is carried much farther, the rock supplies en may be affected and the farm owners be reduced to storing rain ater. A remedy for this threatened danger lies in more intelligent lanning of drains, such as following the contours instead of crossing hem, and the use of devices to hold the water back on the land during easons when it can do no harm by its presence.

SUBSURFACE DRAINAGE.

In mining operations it is sometimes necessary to pump from the hafts enormous amounts of water or to drain sand and gravel beds hich are passed through in sinking shafts. In most cases such beds urnish the whole or part of the water used by the people of the region, nd the result of the draining is to cause either entire loss of supply, as here gravels are drained, or partial loss where the workings enter ater-bearing strata at some distance from the wells. Thus the coal nines in Huron, Saginaw, and Bay counties have stopped the flows in number of districts of rock wells which formerly used to flow and are eported to have drained dry considerable areas of shallow drift wells. he same thing happens locally when large waste from flowing wells n low ground is allowed to go on unchecked, and sometimes where for ome manufacturing purpose large amounts of water are pumped rom shallow strata, or where a group of wells is put down for public upply and is pumped sufficiently to affect the amount of water in the ater-bearing strata of a district with a limited catchment area.

QUALITY OF WATER.

In general, all waters from the drift are hard, but in varied degree, some much more so than others. The cause of hardness is the presence of lime or calcium salts, usually the carbonate, but in the lake-plain region sometimes the sulphate or gypsum. In Midland County the drift waters from the deeper wells were of a remarkably low degree of hardness when compared with those of other localities. These hard waters usually have considerable amounts of iron present also, sometimes sufficient to give reddish scale when evaporated. Both the lime and iron are derived much more abundantly from clay beds than from sand, hence the waters drained from clays are harder than those drawn from sand. The calcium and iron carbonates thus derived from the soils are usually acidic rather than normal salts, and are generally accompanied by an excess of carbonic acid, which when the water is exposed to the air at normal pressure and temperature soon escapes as free carbon dioxid. It is this acid, and not the iron in the water, which attacks and destroys unprotected iron pipes and utensils and rusts tinware in which it is allowed to stand. The rusting in the case of the tinware seems usually to start at some point where the tin coating on the iron is thin or broken and spreads from this until holes are dissolved in the iron. The use of so-called galvanized or zinc-coated pipe and utensils or of "granite" ware is recommended as a partial protection against loss in this way.

The drift waters are sometimes saline, but not to a marked degree except in a few areas in the lake plain. It is probably true, however, that the salt content of the waters of the drift in the district covered by this report is abnormally high, because of the great abundance of salt waters in the rocks below the drift, from which they escape through faults or other fissures or abandoned salt wells. More rarely, salt may have been retained after inclusion in the drift. Compounds of magnesium are also present. For fuller statements regarding the waters of the drift, the reader is referred to the separate accounts of the various areas.

The character of the water from the bed rock varies with the nature of the rock, but is usually less hard than that from the drift. It is nearly soft (free from lime) when from certain sandstones, harder from shales, and very hard from limestones or rocks with calcareous cement or from gypsiferous beds. The rock water in certain parts of the lake-plain district is highly salty and in others brackish, and in many cases, where the rock from which it comes is a shale, magnesium compounds are present in considerable amount and may give well-marked tastes which are characteristic. In case the water comes from rocks with iron pyrites or iron sulphide present in it in quantity the water may become impregnated

h hydrogen sulphide, a gas which gives the characteristic "sul-
ır" odor to it, and is particularly prized in medicinal waters.
ɔm the change of the pyrites to the sulphate of iron (copperas),
ich may occur in certain cases, the water may acquire an astrin-
ıt taste, which is not uncommon in water from the shales, espe-
lly those of the sub-Carboniferous and Carboniferous formations.
It may be stated here, however, that the best water for any and
uses, except the manufacture of certain chemical compounds, is
ıt which is free from mineral matter and from organic matter.
ıile small quantities of gases and minerals may do no serious
rm in water used for domestic purposes, large quantities demand
ıt the water should be distilled, if possible, for drinking purposes.
Taken as a whole, both the quantity and the quality of drift as
ll as rock waters in the region studied are excellent, and the local
ɜas where the supply is not adequate or the quality is very poor
ɜ few in number and comparatively small in extent. The natural
ıters from the drift and rock are undoubtedly wholesome, and it
only where they are contaminated from the surface through the
edium of the open-basin type of well or through careless disposal
sewage that they become the cause of disease.

WATER SUPPLIES OF TUSCOLA COUNTY.

GENERAL STATEMENT.

The report on the water resources of this county is based on notes
ıthered by the writer for the Michigan geological survey, made
ailable by the courtesy of State Geologist Alfred C. Lane, who
ıs kindly placed at the disposal of the writer these notes and all
her material bearing on the question in the records of the Michi-
ın survey. With this are a small amount of new material gath-
ed by the writer in a two-days' trip into the more recently settled
ırts of the county at the end of the field season of 1904 and some
ıta collected by correspondence during the same period by Mr.
everett.[a]

TOPOGRAPHY AND WATER SUPPLY.

Tuscola County is situated on the southeast side of Saginaw Bay.
rom the level of the bay the land surface rises very gradually from
2 to 15 miles to the foot of a well-marked morainal ridge and then
pidly to the top of the ridge, which is from 50 to 125 feet in height
ıd from 1 to 3 or more miles in breadth. This ridge enters the
ɔunty a short distance west of the northeastern corner and runs
agonally nearly across it, about parallel to the shore of the bay,

[a] A more extended discussion of the same subject will be found in the forthcoming bulletin of the
chigan Geological Survey on the resources of Tuscola County.

gradually getting lower until it fades into the plain a short distance southwest of Vassar. To the east the ridge descends abruptly to Cass River; in fact, it forms the western boundary of the broad valley in which this stream runs. From this valley, which makes a third distinct area in the county, the land ascends on the eastern side by broad terraces to a sandy plain several miles broad, from which to the southeast there rises sharply a massive moraine which occupies the southeastern part of the county.

The soil of the plain is principally a heavy compact clay or clay-loam, with narrow ridges and broader strips and areas of sand or sandy loam winding across and scattered over it, while that of the morainal ridges is a gravelly clay, or even, locally, a pure gravel, on the whole much more porous than the clay soil of the plain.

In the valley the surface is usually covered with sand, generally of rather shallow depth, but frequently piled up in ridges of considerable extent and height, and the same condition prevails until the ridged or morainal district to the southeast is reached. Below the sand, at varying distances, is a compact, tough, dark clay. In a few places the stream cuts down to bed rock, which is generally a sandstone where exposed.

Corresponding to the peculiarities of topography and soil are variations in the ease with which water is obtained, the quantity obtainable, and to some extent the quality. In the lake-plain district (that bordering upon the bay) the soil is too fine grained and too compact to permit of rapid percolation of water, and the clays are too homogeneous and fine throughout to furnish water in large quantity. In the morainal districts, on the other hand, the surface soils are gravelly and much more porous and permeable, while below the surface strata of sand and gravel are common, easy to reach, and usually contain an abundance of water. Rarely, in the higher parts of the southeastern district, the ridge is wholly made up of compact clay or dry gravel, in which case it is necessary to seek water deep down in the drift or to drill down to rock.

The valley of Cass River, above Vassar, is generally so sandy that most of the rainfall is absorbed by the surface soil and soaks rapidly through to the clay, which lies at varying distances beneath. The usual supplies in this area are obtained from wells sunk to the top of these underlying clays and from springs which appear in the valleys of streams that have cut through the rather shallow sand into the clay. These springs result from the water running along on the surface of the clay to the valley, where it finds an outlet. Below Vassar the conditions are less favorable for the absorption of the rainfall, but are still such that good supplies are usually obtainable near the surface.

LAKE-PLAIN REGION.

It is evident from the foregoing that the only district of this county where there is any especial difficulty in obtaining a supply of water for ordinary domestic uses is that bordering on the bay and lying between it and the foot of the central morianal ridge, for here the soils being very fine grained are not absorbent, and have few coarse layers between the surface and the bed rock, making it difficult to secure readily an adequate supply of water.

SOURCE OF WATER.

SURFACE WATERS.

In the early days of the settlement of the region this part of the county was covered by a heavy swamp forest, and the ground-water level was near the surface; in fact, in many places the ground was flooded during the rainy part of the year, and especially when the snow was going off in the spring. At this time water was easily obtained from shallow dug wells. As settlement, accompanied by clearing and draining, progressed, more and more of the rainfall was carried rapidly away, and, as a natural result, the ground-water level sank until the dug wells gave out or were deepened. In a few cases they were carried down nearly a hundred feet. Usually, however, they were deepened, not by digging, but by boring with large-sized well augers, 4 to 8 inches in diameter. This method was in use some time, but it was soon found that in many areas no permanent supply of water could be had in the clays above the bed rock, and the next development was the driven well, reaching down nearly to the rock surface, where, as in other parts of the lake plain, a fairly satisfactory supply of water is frequently to be found. In many cases, however, conditions seem to have been unfavorable for storing such a supply, and the drilled well in the rock was the last resort. At the present time, since the region has become more thickly settled and the system of drains has been largely developed, drilled wells reaching down considerable distances into the bed rock are the usual type over a large part of the district.

The surface waters, as they are termed—that is, those which are obtained from shallow dug wells—vary in quality according to the type of surface material, whether of clay or sand. The clay soils were originally so swampy that the water in the wells of the old dug-basin type was never looked upon with favor, and was probably justly condemned, as the conditions were all in favor of contamination from the surface, and the waters probably were frequently the cause of disease, especially when the supply was diminished by drought.

It is evident that the original swamp soil could be easily infected by disease germs, as it was damp, contained large amounts of organic matter, and was easily warmed by the sun in the summer time; that in

flood times, which were frequent, the waters from cesspools, drains, and other sources of infection would be spread over the ground and might, and often did, find their way to the wells; and that in dry times cracks would open up in the clay, on account of shrinkage, and through these water from the contaminated surface, from sinks and other drains, and often from privy vaults, could find a way to the wells. Under such conditions it is not difficult to understand that the dug wells were not in favor in the clay regions. In addition to these considerations, it must be taken into account that the soil contains much finely pulverized limestone, which renders the water hard. And, as was usually the case, when the water contained considerable amounts of organic matter, iron, as well as lime, was dissolved and gave it a strong astringent taste.

In places where there were several feet of sand, however, the water of shallow wells was more wholesome, better in quality, and more abundant, this being due to the filtering power of the sand, which removes and holds near the surface organic matter and disease germs, to its greater permeability, and to the scarcity of lime and iron salts. Cracks and fissures do not easily develop in sandy soils, and hence direct channels between the well water and the sources of contamination are less frequent or entirely wanting. For these reasons, and because the supply of water is so much greater in the sand, dug wells are general in the sandy areas, where the sand is deep enough to afford any permanent supply. Upon sand ridges, especially, the wells are generally shallow open basins dug through the sand to the underlying clay.

DEEP DRIFT WATERS.

In general there is very little water in the clay between surface and bed rock. The clay is too fine and too compact to be porous and on this account absorbs little water, and is too slowly permeable to yield it up readily even where nearly saturated. The clay seems to have been laid down under water, and has very little embedded gravel or sand into which water can penetrate and accumulate. Where water-bearing strata are found, however, the water is healthful, but is hard and contains much iron. These water-bearing strata in the clay are thin, limited in area, and occur at all depths, but are not generally depended on as sources of supply in the flat lands.

A more constant source of supply utilized over a wide area, and not infrequently yielding flows, is a porous stratum just above the bed rock. This seems often to be bowldery gravel lying on the rock surface, and is from one to several feet thick. This generally yields a good supply of water, which is frequently so like that from the rock itself that the natural inference is that the water comes from the rock and is forced from it into the overlying gravel by pressure. On the

other hand, it not infrequently happens that the water in the rock will be brackish while that above will not taste of salt at all, in which case it seems probable that the water in the gravel is derived from above rather than forced up from the rock. All of these water-bearing beds may be reached by dug, bored, or driven wells.

ROCK WATERS.

These are of varying character according to geologic formation and the type of rock from which they come. As a full account of these will be published by the Michigan Survey, and as this report deals especially with the drift and its waters, no discussion of the formations and types of rock will be entered upon here, except to state that the water comes from sandstone, or rarely from shales, of the Michigan formation in the eastern and central parts of the district under discussion, and from those of the Carboniferous in the western part. It should also be stated that a large part of the present supply of water for farm and house use in this district comes from bed rock.

The rock water is, in a marked degree, less hard than that from the drift, and in many cases it is so free from dissolved lime or calcium compounds as to give no trace of these by ordinary tests; in a few cases it was reported as "softer than rain water." This softness may be attributed to the absence of calcium minerals from the sandstones in which the water is moving, and also to the probable fixation of the calcium by the action of sodium or magnesium sulphates upon the more soluble calcium compounds. In many cases the purity of the water is such that the first explanation seems reasonable and probable, but in the case of salt and bitter waters, the second is quite as likely to be correct. Three well-marked districts may be distinguished by the character of the water from the rock in this region, as follows:

1. The district of fresh, soft, or relatively soft, water, extending from the foot of the low central moraine westward to the northwest corner of Columbia Township (T. 14 N., R. 8 E.), and thence diagonally southwestward nearly to Reese, whence it runs more nearly due south, finally leaving the county near the northwest corner of Arbela Township (T. 10 N., R. 7 E.). This district may extend still farther eastward than the moraine, but there are few rock wells to show its limits in this direction.

2. A belt a mile or two, rarely more, in width lying just west of the first district in which the rock water is all more or less bitter to the taste of a person not accustomed to it, and is frequently slightly brackish as well. This belt is not well marked at the northern end, but is easily traced across the county. This bitter water is so free from lime and its compounds that it seems probable that a chemical

precipitation of the calcium salts as the sulphate has occurred, and that soluble magnesium chloride has been formed, to which substance the water owes its bitter taste. In general these bitter waters show only a small amount of sulphate present, but considerable amounts of chlorine, leading to the conclusion that the bitter taste came from magnesium chloride rather than the sulphate; however, no very careful examination of the water was made.

3. An area immediately west of the last, lying between it and the bay, contains brackish water from the rock, or, frequently, salt to such an extent that it is unfit for cooking and can be used for watering cattle or for drinking only when one has acquired a taste for it. The saltness of the water increases as the district is crossed from east to west. In the western part also the waters near the rock surface are more likely to be usable, the deeper ones much less so. In one small area in Wisner Township, near Saginaw Bay, the drift wells, even where shallow, were said to be salty and it was reported that in early days "deer licks" were formed in this vicinity, an indication either of a percolation upward from the rock surface by the salt water or the pressure of direct fissures, not improbable in a region where the bed rock is known to be more or less faulted. These salt waters were often very nearly without hardness, showing only small traces of the calcium salts.

The salt comes from the shales and sandstones of the coal measures, which are strongly saline in this region. The deeper beds of the Marshall sandstone are also salt bearing, while the upper ones yield little or no trace of salt, this substance having been leached out, possibly, as suggested by Lane, by the great draft on the lower brines by the salt-manufacturing industry in Saginaw Valley. Whatever the cause the salt is gone from these beds, but at lower depths the water, even from the Marshall sandstone, is salt, so that wells in the lake plain more than 300 feet in depth are usually salt or brackish.

Depth to rock.—The drilled wells in the district under consideration are so distributed as to make it apparent that the rock surface is a gently-sloping plain, with at least one well-marked valley in it, and possibly more than one. The slope of the surface of the rock is toward the west and about the same as that of the present land surface (on an average about 10 feet to the mile). Local elevations of the land surface do not usually coincide with those of the rock surface, so there are minor areas in which considerable variations in depth of rock are shown, which would entirely disappear if the land surface were a true plain. On the other hand, there are equally great differences where the land surface is flat.

In the following table it will be seen that the average depth to rock in the various townships is relatively uniform, varying only about 20 feet from the lowest, found in the northern and western part of the

the highest, found in the extreme southern part. Wisner p has the lowest average and the least variation, but three ıkron, Columbia, and Fairgrove, show an average depth but ›t greater, although the surface of the county is more uneven ı many feet higher.

Rock wells of Tuscola County.

Township.	Township, N.	Range, E.	Number of wells reported.	Number of wells in which rock is over 100 feet deep.	Depth of rock.		
					Greatest.	Least.	Average.
					Feet.	*Feet.*	*Feet.*
.....	14	7	7	0	85	70	77
.....	13	7	76	11	170	70	86
.....	12	7	45	8	140	60	89
.....	11	7	9	3	200	49	79.5
.....	10	7	2	1	120	70	95
.....	15	8	51	9	229	60	83
.....	13	8	60	6	230	55	84
.....	12	8	6	4	112	84	98
.....	14	9	70	11	+160	50	83.6
	.....	.....	326	53	+230	49	81

'eatest depths occur in certain restricted areas which seem to tely related to each other and indicate that there is a buried :tending from Huron County southwestward beneath the vil- 'nionville, across Akron and Fairgrove townships into Gilford ımark, where it is lost track of. This valley is of interest, ›laces it furnishes abundant supplies of water, sometimes with ›ad, so that fine flows are obtained from it, but in other places to contain little water, and when struck increases the cost of ›ing by adding to the number of feet of casing required to d rock.

FLOWING WELLS.

›ution.—Over a considerable part of the lake-plain area the ›m the rock is under sufficient pressure to rise nearly to, if not he surface of the ground, and there are in consequence many well districts. It might almost be said that the whole area tes a single district, for the water will overflow the surface is is low or when very permeable strata are struck; but in here the surface elevation is high or the water-bearing strata fine grained a flow will not be obtained. The low-lying dis- ›pressions, and valleys, then are the places where flows are ı the largest numbers. Even slight ridges are sufficient to the flows. The largest areas of flows were found in Columbia :p, where depressions of several square miles in extent exist, whole of which it may be possible to secure good flows of t water from the rock, and in occasional wells almost equally ›plies from the drift near the rock surface.

Extending west and southwest from this township are numerous other areas, usually of small extent, in which both rock and drift flows are found, the water usually flowing in good quantity, but being, as already pointed out, often brackish or salty in the western part. The water from the drift where flows of this type occur was reported to come from near the surface of the rock and may get its pressure from the rock itself.

Loss of head.—In northern Akron Township, north and west of Unionville, are several small flowing-well areas in which the flows have greatly diminished or in many cases entirely ceased. The date at which the failure began was so closely connected with the opening and working of the coal mines at Sebewaing that the owners attribute the loss of head to the immense drain on the underground waters which the operations in these mines entailed. The connection between the two phenomena is the more close when it is considered that the wells to the eastward of what is assumed to be the border of the lowest beds of the coal measures were not affected, as they draw their supplies of water from beds which are below the ones worked for coal at Sebewaing.

Loss of head was noted at many other points where single wells, usually on high ground as compared with the others in the same area, were reported to have flowed formerly. Not infrequently the time when the flow ceased could be fixed by the date when some neighboring well on lower ground was completed. In a few cases, deepening a well was reported to have restored the flow after it had ceased.

During the excitement attendant upon the development of the coal deposit about Saginaw many holes were drilled by coal prospectors, which after the drilling was completed were plugged more or less perfectly and the casing pulled out. In some cases, because of imperfect plugging, the water from the rock worked its way out to the surface, and, flowing freely, was the cause of diminution or loss of head for several wells in the neighborhood.

It has already been pointed out that the rock surface rises from the bay eastward. At the shore of the bay the altitude of the rock surface is about 520 feet above sea level, or about 60 feet below the bay; near Cass City it crops out in the bed of the river at an elevation of about 700 feet above the sea; while to the northeast at Tyre it rises in places to about 800 feet. These elevations are important, as they show a steady increase in the height of the rock surface, sufficient to give pressure to the water at the lower elevations, especially since the dip is from the higher to the lower elevations. That these differences are really sufficient is evident when it is remembered that the majority of areas of flows occurring in the lake-plain district are below the 660-foot surface-contour line, and none are above the 680-foot contour, that is, the surface in the flowing-well areas in Columbia, Akron,

d Fairgrove townships is from 30 to 50 feet or more below the sur-
:e of the rock in the valley of the river a few miles to the east, and
ıch more below what it is a little farther northeast. In the same
gions, where the rock surface is higher, the surface deposits are very
sorbent, and a much larger percentage of the rainfall penetrates
e ground and finds its way into the permeable sandstone than in the
ıy-covered districts. These areas supply much of the water as well
the pressure of the flowing wells.

In this connection it may be well to note that the rather porous
ɔraine, or high ridge, between Cass River and the flowing-well
eas under consideration is also a catchment area of considerable
ıportance, and if the clay underlying it is as penetrable to water as
; own surface a large part of the rock water, and the head as well,
uld be derived from it. One objection to such an hypothesis is the
eat scarcity of lime in the rock water compared with the amount of
ne and other mineral matters in water from the drift, which could
ırdly be eliminated in the passage of the water through the rock.
ıe sandy areas to the northeast and east would not yield the
luble minerals, hence are the more probable sources of supply.

Flows from drift.—In the lake-plain district flows from the drift
'e rare compared with those from the rock. The largest area is
tuated a mile southeast of Unionville, and is about a square mile in
ctent, the group consisting of eight or ten wells which have good
ɔws, with a head of from 3 to 5 feet. The depth of these wells is
om 50 to 75 feet, and most of them get their water from a stratum
: quicksand which lies upon the surface of the bed rock, from which
eighboring wells draw their supply at slightly greater depth.

The water of these wells is generally of about the same character as
ıat from the rock, and it is probable that it finds its way into the
ınd from the rock, rather than from the clay above.

A small group of flowing wells from the drift also occurs a mile west
f the town of Akron. As in the Columbia area, these go down nearly
o the rock surface and get their water from quicksand or fine gravel
ust above the rock.

Aside from these areas there are about thirty small areas with one or
wo wells each, located near or in areas of flows from the rock,
hich present about the same characteristics as the two areas men-
ioned above. In all of these wells, with possibly one or two excep-
ions, the water comes from near the surface of the rock, and it is
ifficult to say whether the wells should be classed as drift or rock
ells, since it seems probable that the water comes from the rock,
hile the wells extend only into the quicksand, which is part of the
rift.

It was reported by one of the early settlers that the first well to flow
ı the northern part of Tuscola county was a dug well about half a

mile south of Unionville, put down, or deepened in a very dry time, until it had penetrated the clay about 90 feet. The diggers left the hole at noon to go to dinner, and when they returned the well had a large amount of water in it, and soon was flowing over the top. This well was the means of showing the farmers of the region that abundant water was to be obtained near the rock or from it, and deep wells, bored or driven, soon became common.

As has already been pointed out, the districts where the soil is sandy or gravelly get sufficient water for ordinary uses from shallow dug wells from 10 to 40 feet deep. The eastern border of the plain, where it approaches the foot of the ridge which marks the limits of the flat lands, becomes sandy or loamy, and is much more permeable than the clays, and furnishes much more water in the upper layers of the drift. Here also are ridges of gravel or sand making former shore lines and extending for many miles parallel to the high ridge to the east, and these furnish extensive reservoirs of water which appears in dug wells, or in the form of springs at the edges of the ridges, or in marshy areas bordering them. The whole length of one of the best marked of these wave-formed ridges is bordered by large springs, some of which are impounded for domestic uses, in one or two cases forming good-sized fish ponds. The water from these springs is medium hard, fresh, and of excellent quality, and often the quantity is large, especially after the outlets have been enlarged. The wells in such localities are usually only a few feet deep and yield an abundance of water.

MORAINAL REGION.

GENERAL CONDITIONS.

The height of these districts above the level of the bay, amounting to about 200 feet in the western and from 300 to 400 feet in the southeastern portion, makes the rock surface hard to reach, and precludes getting flowing waters from the rock, and on the highest land from the drift. The greater permeability of the surface soils of the ridges compared with the clays of the lake-plain district permits a much larger percentage of the rainfall to be absorbed, while the unsorted and loosely compacted subsurface materials serve to give storage to the water thus absorbed at no great distance down. In these districts the wells are usually of the open dug type, of depths varying from 12 to 60 feet, beyond which they are sometimes deepened by boring or drilling. In a few cases it was found that wells had been drilled through the drift to the rock, sometimes nearly 300 feet down; but this is rarely done.

The location of wells in the morainal districts is often most disadvantageous, since they are placed on or near the top of the ridges, where the water table or zone of permanent ground water is the far-

est possible from the surface, and is much more subject to fluctuations an it is in the depressions or near the bottoms of the slopes. Even ien a well gets its water from a gravel vein it is evident that the ıter is much more quickly exhausted, at least so far as a given well concerned, if it is tapped near the top of a slope than at or near the ttom, because of the effect of gravity, which is constantly drawing e water down the slope and away from the higher levels. The epest well of which record was obtained in these districts was one the northwest corner of Watertown Township, which was reported be 352 feet deep, with bed-rock at 272 feet from the surface, the ;itude of the surface being 900 feet above sea level.

The water from the wells of the morainal districts is variable in the ıount of the dissolved mineral matter which it contains, consisting iefly of lime or of calcium and iron compounds. It is harder in clay ·ata than where it passes through sand and gravel. No saline or ackish water known to come from the drift was found in these areas.

FLOWING WELLS.

Near the foot of the steeper slope from the high morainal district ward Cass River are five small areas of flowing wells from the surce deposits or drift and one from the rock. On the southward slope om the same ridge, extending also into Lapeer County, is still another ·oup.

Two of these districts are situated in Arbela Township, one in Waterıwn, one in Fremont, and one in Wells, on the north side of the ridge, nd one in Dayton Township on the south side. The others are small ı the extent of area covered, embracing from one to three wells.

ARBELA TOWNSHIP.

The first area in Arbela Township is on the line between secs. 14 nd 15, where the wells are about 30 feet deep, with a slight head of ather hard water. The well on the farm of D. N. Van Wormer, for ıstance, is 27 feet deep, having surface clay and gravel to 10 or 11 eet and hardpan thence to the bottom.

The second area is on the east side of sec. 13, and consists of two ·ells 60 feet deep. These are at the foot of the sharp slope of a ridge, nd the water was reported to come from gravel, was hard, and conıined iron. It flows with a head of about 2 feet, and discharges less ıan 1 gallon a minute.

The sources of head and the catchment area are apparently in the dge lying to the south, which is the westward extension of a higher ıoraine to the east.

If this ridge is the catchment area, there seems to be no good reason hy the present areas should not be extended both east and west of ıe present development over an area extending a mile, more or less,

from the foot of the steeper slopes and flows obtained from various depths. This seems the more probable because in Saginaw County the same ridge and conditions exist, and the area of flows is much larger than here.

In the center of Arbela Township, at the town hall, is a flowing well 270 feet deep. The record is as follows:

Record of well in Arbela Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface clays and hardpan	70	70
Shales	194	264
White sand rock yielding a flow	6	270

FREMONT AND WATERTOWN TOWNSHIPS.

Both of these townships, which have each a single well in the present stage of their development, lie near the foot of the high moriane in the southeastern corner of the county 4½ miles west of Mayville. The Fremont well was not visited, but was reported to be about 70 feet deep and to flow a good stream. From the situation and topography it seems likely that flows might be had northeast and southwest of the present location. The well of Mr. Arthur Wills, in Watertown Township area, is situated 1 mile south and 5½ miles west of Mayville, on the north side of sec. 6. It is 65 feet deep, has a 2-inch casing, which is reduced at the outlet to one-half inch by a valve used to shut the water off so it will flow to the barn. The flow is about 5 gallons a minute, with a head of more than 6 feet, and but for the reduction of the size of the outlet the water would apparently flow the full size of the pipe to this height. The water has a temperature of 49° F., is hard and contains considerable iron, and is of good quality. It seems probable that this area could be connected with the Fremont area and extended to the west and south along the gentle slopes at the foot of the high ridge, but the district is at present sparsely settled and the rather sandy till yields sufficient water for general uses in open dug wells of slight depth.

WELLS TOWNSHIP.

This area is situated in a recently cleared district on secs. 27 and 34, 1 mile north and 4½ miles west of the village of Kingston and about 11 miles southeast of Caro. The district is at present less than 1 mile long and contains two wells 43 and 48 feet deep, respectively, which derive their water from gravel. The head is about 18 inches and the flow from 1 pint to 1 quart a minute. As these wells are near the foot of the slope from a high ridge to the south, they prob-

ably derive their head and supply from this source, and the area may be capable of extension both east and west along the same level and possibly also north of the present area.

Along the foot of the moraine, where it crosses secs. 25 and 36 of Wells Township, is the outcropping of a more compact, less permeable clay, under a gravel deposit of considerable extent. The clay exposure forms the lower part of an extensive slope, down which the water which runs out upon it from under the gravel finds its way, often forming springs of considerable size. One of these springs appears by the road on the northeast quarter of sec. 36 and flows into the roadside ditch. The water comes from sand, is hard, contains iron, and is of excellent quality. The amount of water furnished by this spring was about 15 gallons a minute after a long period of drought. The whole district along the base of the ridge is more or less favorable for such springs.

VALLEY REGION.

Cass River Valley, in Tuscola County, is a well-defined district in which the water-supply conditions differ from those in either of the other districts. The Glacial or lake history of the valley explains the generally sandy nature of the surface deposits throughout the upper and central parts of the districts, but can not be entered into in this place except to state that this valley was first occupied by ice, then by an arm of the Glacial Lake Saginaw, into which flowed a large stream from the melting ice to the north. This lake subsided by slow stages, leaving shore and shallow-water deposits in the form of sand, which was either heaped up into ridges or spread out in thin layers over the surface by the falling waters. The stream constantly brought down more sand, which was built into bars and deltas. All of these deposits are readily permeable to water, and nearly all of the rainfall upon the surface is readily taken in by the coarse soils. This either runs off below the surface or remains in hollows upon the top of the clay subsoil or upon the top of the rock, where this was the underlying stratum, as it is in the northeastern part of the county.

As the result of this structure and history, in most parts of the area shallow wells, dug down to the surface of the clay or into it a short distance, furnish a good supply of water.

Aside from this ease of getting water in shallow wells, the district is much more fully watered than either of the other districts by small streams tributary to the river. These and the river furnish water for stock in large quantity. The valleys of the streams, and of the river as well, in many places cut through into the clay underlying the sand. This clay is dark colored, very hard and compact, and is probably of greater age than the surface clays of the other districts. It is nearly impenetrable to water. Along the junction of the sand and clay the water flows *out into the valleys*, forming springs, which vary in size

y derive their head and supply from this source, and the area may capable of extension both east and west along the same level and sibly also north of the present area.

Along the foot of the moraine, where it crosses secs. 25 and 36 of lls Township, is the outcropping of a more compact, less perme- e clay, under a gravel deposit of considerable extent. The clay osure forms the lower part of an extensive slope, down which the ter which runs out upon it from under the gravel finds its way, en forming springs of considerable size. One of these springs ears by the road on the northeast quarter of sec. 36 and flows into roadside ditch. The water comes from sand, is hard, contains n, and is of excellent quality. The amount of water furnished by s spring was about 15 gallons a minute after a long period of drought. e whole district along the base of the ridge is more or less favorable such springs.

VALLEY REGION.

Cass River Valley, in Tuscola County, is a well-defined district in ich the water-supply conditions differ from those in either of the er districts. The Glacial or lake history of the valley explains the erally sandy nature of the surface deposits throughout the upper d central parts of the districts, but can not be entered into in this ice except to state that this valley was first occupied by ice, then an arm of the Glacial Lake Saginaw, into which flowed a large eam from the melting ice to the north. This lake subsided by w stages, leaving shore and shallow-water deposits in the form of d, which was either heaped up into ridges or spread out in thin ers over the surface by the falling waters. The stream constantly ought down more sand, which was built into bars and deltas. All these deposits are readily permeable to water, and nearly all of the infall upon the surface is readily taken in by the coarse soils. This her runs off below the surface or remains in hollows upon the top the clay subsoil or upon the top of the rock, where this was the derlying stratum, as it is in the northeastern part of the county. As the result of this structure and history, in most parts of the area allow wells, dug down to the surface of the clay or into it a short stance, furnish a good supply of water.

Aside from this ease of getting water in shallow wells, the district much more fully watered than either of the other districts by small eams tributary to the river. These and the river furnish water for ck in large quantity. The valleys of the streams, and of the river well, in many places cut through into the clay underlying the sand. is clay is dark colored, very hard and compact, and is probably of ater age than the surface clays of the other districts. It is nearly penetrable to water. Along the junction of the sand and clay the flows out into the valleys, forming springs, which vary in size

from seepage lines scarcely recognizable to large outflows of many gallons to the minute, such as the springs from which the town of Caro draws its water supply.

This area, however, is the least thickly settled in the county and is likely to remain so, because of the small agricultural value of much of the land; hence the water resources are poorly developed and little utilized.

At Tuscola, Vassar, and Caro, and in the immediate vicinity of these towns are a few rock wells, which will be considered in connection with the water supplies of these towns.

MISCELLANEOUS TOWN SUPPLIES.

Each of the districts described above has some of the towns of the county located within it, and in general it may be said that the village supplies in each district are characteristic of that area in which they are obtained.

LAKE-PLAIN REGION.

UNIONVILLE.

This village, with a population of 457, has no public supply and gets the water for domestic use and for manufacturing from wells, which in many cases penetrate the rock here from 90 to 150 feet below the surface. The greater depths occur in the eastern part of the town, where the depth varies abruptly from the least to greatest, indicating a valley in the rock, as the land surface is nearly level. A few of these wells flow, but usually the water is pumped, and is soft and fresh and in good quantity for all present needs.

In case a public supply is required the rock should, from present indications, furnish a good and very pure supply, and if the wells were put down in the lowest possible places they would in all probability flow.

AKRON.

This village is situated on a low, broad, sand ridge. It has two sources of supply, the clay under the sand and the rock deep down below the clay. There is no public supply, and a large number of the people get water for domestic use from shallow dug wells 10 to 15 feet deep.

As this supply chiefly comes from water which leaches through the shallow sand, it is more or less likely to be contaminated by percolation from cesspools, drains, and vaults. Such wells, especially in dry times, are unsafe unless every precaution is taken to guard against pollution. As the population increases, these shallow wells will have to be abandoned, as the supply is limited because of the small catchment area, and even at present is noticeably affected by dry weather.

driven, and drilled wells in the neighborhood reach rock at feet and same penetrate it to a depth of 100 or 150 feet. these rock wells flow 3 or more feet above the surface. The fresh and nearly soft, but has a slightly bitter taste, not e except to those unaccustomed to its use. If the town ever a public water supply, the rock will be the best available ıough wells to it probably will not flow unless located on the nd or off from the ridge. The upper strata of rock seem to , so, for a large supply, the wells must be sunk to underlying e at considerable depth.

FAIRGROVE.

llage is situated on a low, broad, morainal clay ridge, some- ›ve the surrounding plain, and is too high to have flowing n from the rock. The town has a public water supply for ›ction and sprinkling purposes, the water being obtained 'ace supplies distributed from cisterns. Supplies for domes- arm use are obtained from dug wells ranging from 12 to 35 ›pth, and from driven or drilled wells which reach or enter The water of the dug wells comes from sand or gravel beds ift and is hard, but otherwise of good quality, except in the ›t wells, in which it is liable to contamination from the

›pth to the rock surface is from 90 to 100 feet and more. est well in the village is probably that at the railroad station, y Mr. McMillen in February, 1895, of which the following ›s been preserved:

Record of well at Fairgrove station.

	Thickness.	Total.
	Feet.	*Feet.*
ırth, clay, etc.)	98	98
solid and hard	2	100
vel cemented[a]	4	104
	11	115
	13	128
shale	7	135
	26	161
	54	215
ındstone	10	225
	18	243
	34	277
	6	283
	16	299
	6	305
ıe rock	7	312
	3	315
ıy lime rock	10	325
shale	8	333
k	12	345
	2	347
k	10	357
ne	31	388
›ck	½	388½

and gravel had *plenty of water in it*, which rose to within 12 feet of the surface. No water

This well furnished a large supply of good water. If the record is typical of the locality, it is evident that the most easily obtained supply is from the layer of cemented gravel near the surface of the rock. Below this level shales are likely to predominate, and do not furnish good supplies of water.

REESE.

This village, with a population of 427, is located on the slopes of a somewhat gravelly morainal ridge, and spreads out upon a plain at its base. As in all cases where there is a porous surface stratum with less pervious strata below, shallow dug wells are the chief source of water supply for domestic use. Here this type of well is reported to vary from 12 to 20 feet, rarely more, in depth, and to furnish a sufficient supply of hard water. The public supply comes from wells of this type, and is pumped for fire protection, sprinkling, etc., but is not used much as yet for other purposes. Aside from these shallow wells, others are drilled and driven down to and into the rock, which here ranges from 80 to possibly 100 feet from the surface. The following record of wells in Reese shows the character of the strata passed through:

Record of well No. 1 at Reese.

	Thickness.	Total.
	Feet.	*Feet.*
Stiff blue clay	45	45
Soft blue clay	27	72
Sand and small sandstone	7	79
Soft soap rock (shale)	7	86
Harder soap rock	3	89
Soft soap rock	14	103
Soap or white chalk rock	2	105
Sand rock	1	106
White hard slate rock	1	107
Black soap rock	4	111
Soft soap rock	3½	114½
Hard slate rock	1½	116
White soap rock	1	117
Black soap rock	4	121
White soap rock	3	124
Sand soap rock	4	128
Sand rock with 4-inch coal bed	5½	133½
Brown soap rock	9½	143
Gray sand rock	4	147
Brown soap rock	3½	150½

Record of well No. 2 at Reese.

	Thickness.	Total.
	Feet.	*Feet.*
l clay	12	12
e clay	66	78
vel and sand	2	80
d lime rock	6	86
brown soap rock	3	89
d white chalk rock	9	98
soap rock	13	111
d white sand rock	4	115
te hard soap rock	2½	117½
y flint rock	½	118
kish soap rock	9	127
k slate rock	2½	129½
ite chalk or soap rock	1	130½
d sand rock	3	133½
lte chalk rock	½	134
d sand rock	3½	137½
k slate	½	138½
d rock	4½	143
k slate	2½	145½
wn slate	5	150½

The water from the rock wells here is brackish or salty; the deep-, which formerly flowed, found strong brine from white sandstone about 430 feet.

RIDGE REGION.

Of the ridge region nothing need be said aside from what has al-ıdy been noted in connection with the general discussion of these strıcts.

GAGETOWN.

This town, with a population of 400, is near the northern county ıe, upon the crest of the western moraine. Dug wells with a depth 10 to 40 feet or occasionally more are the most common source of pply for domestic use. The water comes from sand or gravel beds the clay, is hard, of sufficient quantity for ordinary demands, and said not to be affected by the seasons. It rises in some of these ells to within 10 feet of the surface.

Wells are occasionally drilled to rock, but no records of the depth ere available. The deepest well in Gagetown is reported to be 140 et.

KINGSTON.

This village, with a population of 350, is located on a morainal dge, 30 to 40 feet above the bottom of the valley in which the rail-ıad runs. The wells are generally dug, and range from 20 to 50 feet ı depth, with an average of 35 feet; the water is hard, but of good uality, and sufficient quantity for domestic use, and is said not to ary with the season. The supply comes from sand or gravel beds ı some of the wells.

A waterworks system owned by the village was installed in 1902, he water being pumped from a 4-inch drilled well 217 feet deep,

which reaches rock at about 150 feet. The water comes from sandstone and rises to within 10 to 12 feet of the surface, giving ample supplies. It is distributed from a standpipe, and is used for fire protection, sprinkling, and boilers. There is also a well 215 feet deep, in rock, at the schoolhouse, having the same characteristics as the waterworks well.

Along the railroad and at the bottom of the valley west of it, both of which lie 15 to 20 feet below the water level in the waterworks well, it is probable that water from the same source would be reached at about 185 feet or a little more, and would flow with strong head. In this valley is a small stream, and along the margin of it are seepage springs, the water from which is sometimes used.

MAYVILLE.

This town, with a population of 750, is the most elevated in Tuscola County, the moraine rising to nearly 1,000 feet above sea level within its limits. As a result of this situation the wells for domestic supply are often deep, but do not reach the rock surface. There is no waterworks system; one was projected some years ago, but was abandoned on account of the difficulty of getting water in sufficient quantity.

A test well was drilled 400 feet and bed rock was reached at 285 feet. In this well water rose from sandstone about 300 feet or to within 100 feet of the surface.

The dug wells are often shallow, from 15 to 20 feet deep, the shallowest being only 10 feet, but driven wells in the higher parts of the town often go down nearly or quite 100 feet to water of sufficient quantity. The water in the shallow wells is said to come from sand or gravel beds in the till, is hard, and is never large in amount; yet the supply is fairly constant, so that moderate demands on it are met except in very dry weather, when it may fail.

Bed rock is the most available source for a large supply for the town, but the great depth to which it is necessary to go to reach rock, and the depth from which water must be pumped makes it an expensive source. If, however, wells were put down in the lowest part of the town, or, better still, in the valley north, and pumped from these to a reservoir in the highest part of the town from which it could be distributed, it seems probable that a satisfactory supply may be had. Nearly 100 feet in the depth of the wells could be saved by locating them in the lowest part of the valley, which runs through the eastern part of the town.

MILLINGTON.

Millington, with a population of 632, is situated on a broad, gently sloping, sandy, and gravelly plain, which is on the edge of the rolling country and is morainal in its origin. The surface soil is permeable enough to take in a considerable amount of the rainfall, and this accu-

ulates in the underlying gravels, which lie from 15 to 20 feet below .e surface. This supply is easily reached by open dug wells, and is rgely drawn upon, the majority of the houses of the town depending a wells about 20 feet deep for their supply for domestic uses. This pply is uncertain and affected by drought. Persons requiring larger pplies drill down to bed rock for water, reaching it at from 90 to 2 feet. In this rock, which is sandstone, water may be found at rying depths in good quantity and of excellent quality.

In 1904 the village completed its public waterworks, the water being tained from two 4-inch drilled wells 187 feet and 200 feet deep, spectively, located near the center of the town. The rock surface about 110 feet down, and the rock was reported as sandstone the hole distance until water was struck. The water rises within 17 feet the surface and is said to be of excellent quality and abundant. It distributed from an elevated tank or standpipe, into which it is mped from the wells.

FOSTORIA.

This village lies on a slope from the high moraine to the north and, far as learned, gets its supply for domestic use from dug wells 20 to feet in depth. A stream flows through the edge of the town, and om this some water is taken for use in boilers.

CASS RIVER VALLEY REGION.

CASS CITY.

This village, with a population of 1,212, has for its site a broad gravy terrace about 40 feet above the bed of Cass River and has behind to the north, a well-marked morainal ridge. The gravel gives undant water in dug wells about 20 feet deep, some going deeper, d these are the common sources of supply for domestic use.

CARO.

This town, with a population of 2,268, is located at the foot of a ell-marked morainal ridge upon a gently sloping or nearly flat gravly terrace of the river valley. It is well situated for the development f a system of waterworks, depending on gravity for the distribution f the water from a properly located standpipe. For several years ch a system, owned and operated by a private company, has been use, the water being pumped, in part, at least, from springs located cross the stream opposite the town. Recently the supply has been ugmented by drilling wells into the rock. The standpipe is situated the northern part of the town upon a morainal ridge about 100 feet bove the principal business street. The water is of good quality nd that from the springs is relatively soft. The springs have their atchment areas to the east of the river in the gravel and sand ter-

races, the town standing on the west, the water percolating through the gravel and sand down to a dense clay substratum, upon which it finds its way until it reaches some place where streams cut this in running to the river, when it flows out as springs. The water is used for all purposes, including domestic and drinking, but there are many dug wells in the town from 16 to 20 feet deep which, upon the gravel flat, reach through the gravel to the top of the clay and intercept some of the water moving along upon it. This water is reported as soft and pure, but unless care is taken to dispose of sewage eventually the gravel will become so contaminated that the wells in the more thickly-settled parts of the town may be unsafe to use and will afford breeding places for the germs of various diseases.

The following is the record of the deep well of the Peninsular Sugar Company; the altitude of the mouth is 15 feet above Cass River, and about 645 or 650 feet above the sea level:

Record of Peninsula Sugar Company's well, Caro.

	Thickness.	Total.
	Feet.	*Feet.*
Drift (sand, gravel, hardpan, and bowlders)	113	113
Limestone	7	120
Shale (blue)	25	145
Sandstone (very soft; first flow of water, 50,000 gallons in 24 hours, soft; rose 5 feet above derrick floor)	40	185
Limestone	5	190
Sandstone	50	240
Shale, black	2	242
Sandstone	10	252
Shale	1	253
Sandstone	29	282
Streak of sandy limestone.		

At 275 feet a flow yielding 350,000 gallons in 24 hours was struck. The water has a slight mineral taste, leaving a sweet aftertaste, probably of magnesium sulphate. The well is 8 inches in diameter; temperature, 47° F.

VASSAR.

This village, with a population of 2,032, is the third important valley town to be considered, and like Caro is located upon the terraces of Cass River, but unlike that town reaches across the stream to the eastern bank. A considerable part of the town also lies upon the morainal ridge, here relatively low and inconspicuous. The ridge is covered with gravel, and hence is more permeable than such ridges usually are.

The village owns its waterworks system, the water being derived from seven drilled flowing wells, which average about 200 feet deep. The deepest well is 230 feet, but is cut off at 200 feet. At the depth of about 125 feet a small flow was struck, and this increased with the depth until it reached its greatest volume at 175 feet, when the flow was about 100 barrels an hour. The total depth of one of the

er wells is 207 feet, with the rock surface at about 50 feet. The er rises 4 or 5 feet above the surface and is pumped to a stand- on the ridge, from which it is distributed. It is relatively soft, ng only a slight powdery scale after prolonged use in boilers. following analysis by Dr. R. C. Kedzie, of the agricultural col-, was made about the time the system was installed:

Analysis of Vassar public water supply.[a]

	Parts per million
l solids	271.43
tile at red heat	71.43
Total mineral matter	200
ral composition:	
Calcium (Ca)	65.49
Carbonate radicle (CO_3)	100.82
Sulphate radicle (SO_4)	20.16
Magnesium (Mg)	6.17
Chlorine (Cl)	4.32
Sodium (Na)	2.82
	199.78
ates and nitrites	None.
ammonia	.05
iminoid ammonia	.04
dness by soap test	85.71
nanent hardness	57.14
Total hardness	142.85

he amount of water yielded by these wells is about 110,000 gal- s a day. Two deep wells were put down at Vassar; one near the road junction, which has a depth of about 600 feet, flows a con- erable quantity of brackish water, which has been bottled and l for medicinal purposes; the other, which was put down as a well about the time the waterworks were established, is 467 deep, and gave salt water of 6 degrees of saltness. This well reported to be plugged and abandoned.

Dug wells from 20 to 30 feet deep are frequently used, furnishing icient water for domestic use, and private drilled wells from 45 200 feet deep are not uncommon. Most of the latter flow when ated on the lower terraces of the river. The rock water is gen- lly softer than that from the drift, especially that from sand- ne, the most common source.

xpressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic and parts per million at United States Geological Survey.

TUSCOLA.

This village, with a population of 275, lies a few miles southwest of Vassar on the lower terraces of the river valley, here somewhat sandy and relatively narrow. The town is spread over both banks, the parts being connected by a bridge. The general sources of water for domestic use and for stock are shallow dug wells from 12 to 40 feet deep, the most common depth being about 20 feet. The water usually comes from strata in the clay which underlies the shallow surface sand and rises within 6 feet of the surface in some of the wells. The water is hard and the supply constant and sufficient in most cases for the needs of the owners.

A few drilled wells on the higher slopes of the valley yield excellent supplies of somewhat brackish water from the rock at about 175 feet in depth. A drilled well at the north side of the village is reported to be 175 feet deep in sandstone, the rock surface being struck at 49 feet. This well flows several gallons a minute, with a head of 2 feet. It is situated on land 30 feet above the level of the river, higher than most of that on which the village is located, hence it would seem probable that other flows could be developed by going down into the rock. The rock surface was reported as 70 feet in another well, but as it appears in the bed of the river a short distance northeast of the town it is probable that this well was on higher ground than the flowing well above cited.

WILMOT.

This small village is situated on the southern edge of the broad sloping plain which rises to the morainal region on the south. The generally sandy or loamy character of the soil, and the fact that it is underlain by clay at moderate depths, makes the water supply good and easily obtained. The wells average about 20 feet in depth and give a good supply of hard water, which is not easily exhausted. No rock wells have been put down in this vicinity.

DEFORD.

This is the next station north of Wilmot on the Pontiac, Oxford and Northern Railroad, and is in much the same situation as Wilmot. The plain is slightly flatter and somewhat sandier. Water is obtained from shallow dug wells at about the same depth as at Wilmot.

SILVERWOOD.

This is a small village on the Pere Marquette Railroad, on the southern border of the county, and is interesting from the fact that a part of its water supply is obtained from flowing wells from the

. The area extends southward into Lapeer County, forming a l-sized district.[a] The few wells which flow in the village are about ›et deep. Dug wells from 15 to 30 feet deep are also common ces of water for domestic uses. The water tank at the railroad ion is filled with water from a flowing well 40 feet deep.

WATER SUPPLIES OF GENESEE COUNTY.

TOPOGRAPHY.

enesee County lies in the southern part of the district tributary to naw Bay, its county seat being at the city of Flint. The north- ›ern part is a plain which was covered by a glacial lake, the shore hich enters the county from southwestern Tuscola County, near middle of its north line, and runs southwestward, near Clio and hing, to leave the county west of the latter village. There are ll flowing-well districts on the plain or in valleys leading into it ı the southeast. A prominent morainic belt, the continuation he one lying south of Cass Valley in Tuscola County, already ribed, passes across Genesee County in a southwesterly course a t distance southeast of the border of the Glacial lake and crosses t River at the city of Flint. Southeast of this morainic belt is a ı in which one of the best flowing-well districts in Michigan (the ison district) is located, together with several small districts. and south of this plain is another morainic belt with a few small ing-well districts located in depressions among its ridges. The eme southern edge of the county from Fenton westward embraces elly plains, with numerous lakes and marshy depressions separa- the morainic belt just mentioned from a much higher one south of Livingston County.

ıe writer gave attention principally to the flowing-well areas, but informed by well drillers and residents that throughout the ıty wells are generally obtained at moderate depths. The deep ; are mainly along the western morainic belt that passes near t, and there they seldom exceed 200 feet; wells exceeding 100 in depth are comparatively rare.

ıroughout the county a clayey till is the predominating deposit. beds of sand and gravel from which wells are obtained appear to ı thin strips intercalated at various levels in clayey till. The bed- surface is from 50 to 200 feet or more below the drift surface, with verage of perhaps 100 feet for the county.

[a] Discussed by Leverett in Water-Sup. and Irr. Paper No. 182.

PUBLIC AND PRIVATE SUPPLIES.

OTISVILLE DISTRICT.

This village, which stands in a rolling tract in the northeastern part of the county, has a public supply pumped from a small lake into reservoirs in case of fire, but this supply is not used for cooking or for manufacturing purposes. Dug wells are the most common source of supply and are shallow, about 15 feet deep. Driven wells are from 25 to 100 feet deep, an excellent supply being struck at about 60 feet, the water rising in some places within 6 feet of the surface.

The following data of two recent wells that struck rock have been supplied by Grant Parker, a well driller at Otisville. The well of C. D. Doan, in Otisville, reached rock at 158 feet and continued to 220 feet. The rock is sandstone, and the water in it rises to 16 feet below the surface. The well of Robert Hammill, one-half mile north of Otisville, struck rock at 160 feet and entered it only 4 feet. The water rises within 7 feet of the surface.

Southeast of Otisville, at the Traver schoolhouse, in sec. 26, Forest Township, a boring reached a depth of 240 feet without striking rock. Sand in the lower part of the boring rose in the pipe and prevented further drilling. The altitude is perhaps 15 to 20 feet lower than at Otisville, or not more than 800 feet above sea level.

At the gristmill of Mr. Peter Hart, in Otisville, is a flowing well 26 feet deep which has a head of 2 feet and flows 3 gallons a minute. The water is soft enough to be used in the boiler at the mill without forming any scale. This well was put down in 1904 near an old one which had formerly flowed but had become clogged. The elevation of the surface at this well is about 20 feet less than at the railroad station.

CLIO DISTRICT.

In the valley of Pine Run, east of the village of Clio, are two flowing wells which were not visited, but were reported through correspondence with Mr. Fred Tinker, of Clio. One well, in sec. 13, owned by Fred Tinker, is 68 feet deep and flows 1.5 gallons a minute with a head of about 3 feet. The water is from gravel under a hard clay. A weak vein of water was struck at 13 feet. The well shows no perceptible change in rate of flow since it was made ten years ago. The other well is in sec. 23, within a mile east of Clio, and is owned by J. V. Valiquet. It is of similar depth and strength to the Tinker well.

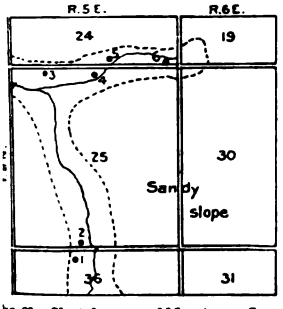
Dug wells in the vicinity of Clio are only 12 to 14 feet deep, too shallow to be safe for continued use, on account of the danger of contamination from the surface. Some driven wells range from 60 to 85 feet in depth, and in some of these the water rises nearly to the surface. The water from the shallow wells is harder than that from the deep ones.

MONTROSE TOWNSHIP.

MONTROSE.

Water in Montrose Township is mainly from dug wells 20 to 40 feet ep. Rock is struck at about 45 feet, and an excellent supply of ater is obtained from it at about 65 feet. The water rises to within or 18 feet of the surface. A public supply for sprinkling and fire otection only is obtained from dug reservoirs.

Near the bottom of the valley of a small tributary of Flint River, or 6 miles southwest of Clio, in the northeast corner of Montrose ownship (T. 9 N., R. 5 E.), is a group of six flowing wells (see fig. 9). The water in these is excellent, not very hard and with little on. The rate of flow is not large in any of them, but is sufficient for e owners, who use it for stock and all domestic purposes. The water rises to about 12 or 15 feet above the level of the creek; hence further development must be confined to the area below that level, which is only a narrow strip along the creek.



ig. 29.—Sketch map of Montrose flowing-well area, Genesee County.

The deeper wells for a mile or more to the west were reported to strike water, which rose within 2 or 3 feet of the surface, and it is possible, since the slope is in that direction, that still deeper wells would strike a water bed with greater head and flows might be obtained. Other than his, as indicated above, there seems to be no possibility of extension f the area of flows except in the valley of the stream at points intermediate between those where they are now present and beyond to he north, quite low down in the valley.

The sides of the valley, especially a broad sandy slope on the west ide of it, may well serve as the intake and storage reservoir.

Fig. 29 is a sketch map showing the approximate location of the ells and the relationship of the valley, etc. The accompanying able gives particulars regarding the wells of the area. They are btained from gravel below a bed of tough clayey hardpan.

Wells of Montrose area (T. 9 N., R. 5 E.).

	Section.	Owner.	When made.	Diameter.	Cost.	Depth.	Elevation.	Head.	Temperature.	Flow per minute.	Quality.	Water bed.
				In.		*Feet.*	*Feet.*	*Feet.*	°*F.*	*Gals.*		
1	36	W. Parmelee and C. McKenna.	1903	2	$60	62	735	+8	52	0.5	Hard; iron	Gravel.
2	25	F. Brown	1902	2	60	60	735	+9	51	2	.....do....	Do.
3	25	William Parker		2	50	50+	725	+8	51	1	.....do....	Do.
4	25	William Hobson		2	.....	60+	725	+7	52	1	.....do....	Do.
5	24	John Hobson		2	.....	60+	725	+7	51	2	.....do....	Do.
6	24	*J. Francisco*		2	.....	60+	723	+9	51	3	.....do....	Do.

BRENT CREEK.

In the vicinity of Brent Creek the shallow wells are 20 to 30 feet deep and are dug. The drilled wells reach 100 feet, and the water from them is slightly salty. The best supply of water is obtained from 75 to 100 feet.

FLUSHING.

Flushing is located on the terraces and sides of the valley of Flint River, in the western part of the county. The soil is generally porous, and the border plains are part of an old lake plain.

The water for the waterworks is pumped from the river, and is only used for fire protection, sprinkling, etc., and not for drinking and cooling. Wells were put down 350 or 400 feet, but struck water too salty to use.

Private wells are the source of supply for domestic use, and are usually from 15 to 20 feet deep, finding water in gravel. Rock is struck at 30 to 80 feet; and some wells have been put down into it, obtaining good supplies of rather soft water at about 100 feet. The deepest well is about 200 feet. Water rises in the deep wells to within 12 to 16 feet of the surface.

FLINT TOWNSHIP.

FLINT.

The city of Flint is located in the valley of Flint River at the mouth of Thread Creek, a southern tributary. The public waterworks take water directly from Flint River above the town, and pump it chiefly for fire protection, sprinkling, and manufacturing.

The following partial analysis shows the composition of the water in the deep wells in the streets of Flint. This water is highly esteemed throughout the town, and is supposed to be of medicinal character; the high percentage of salt and sulphate constituents are its most noticeable features. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of deep-well water at Flint.[a]

	Parts per million.
Color	32
Iron (Fe)	1.2
Chlorine (Cl)	1,042
Carbon dioxide (CO_2)	94.38
Sulphur trioxide (SO_3)	478
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 376 feet.

The valley in which the river now runs is partly filled with coarse dry gravel lying directly on the bed rock, which ranges from about 25 feet deep near the level of the river to 70 feet or more in higher parts

ıe town. Tubular wells extending into the rock are common. · furnish good water and supply many of the residents.

flowing well 376 feet deep on Saginaw street supplies a city ·ting fountain. The water is mineral, containing among other tituents salt and hydrogen sulphide, which gives it a decided taste odor. It is very largely used during the summer months.

; the Oak Grove Sanitarium is a well 265 feet deep, with a large of mineral water. The following analysis was made by Dr. J. E. k, of Detroit:

Analysis of well water at Oak Grove Sanitarium, Flint.[a]

	Parts per million.
m (Na)	663.42
sium (K)	26.64
esium (Mg)	42.25
ım (Ca)	128.46
bonate radicle (HCO_3)	365.88
ıate radicle (SO_4)	165.46
ine (Cl)	1,059.43
and alumina (Fe_2O_3,Al_2O_3)	9.93
(SiO_2)	Trace.
ım	Trace.
	2,461.45

he following record of the strata passed through in the Oak ve Sanitarium well was furnished by Mr. George De Witt, of Flint, drilled the well:

Record of Oak Grove Sanitarium well, Flint.

	Ft.	in.
ce (mostly gravel)	33	
sandstone	85	
rock		8
: slate		10
		10
	2	
sandstone	15	
: slate (fine clay)	5	6
		8
: slate	9	6
ur rock		7
slate	16	
: slate		6
slate	28	
rock	67	6
	265	8

t a schoolhouse about 2 miles south of the city limits in a creek ·y on the Fenton road, at the southeast corner of sec. 25, Flint

[a] pressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic and parts per million at United States Geological Survey.

Township, is a well from rock, small flow, which supplies a w ing trough. There are no other flowing wells in that locality. accompanying table gives the statistics of these wells:

Wells at Flint.

No.	Section.	Owner.	When made.	Cost.	Depth.	Elevation.	Head.	Temperature.	Quality.	Depth to rock.	Ki r
					Feet.	*Feet.*	*Feet.*	°*F.*		*Feet.*	
1	25	School district [a]	1900	$120	111	750	+1.33	52.2	Iron; soft.	±70	Sand
2	25	Oak Grove Sanitarium [b]	.....	200	265	735	+8	51	Mineral water.	33	I

[a] In valley of creek; flow, 1 gallon a minute.
[b] Used for baths and medicinal purposes; flow, 7 gallons a minute.

OTTERBURN.

The wells in this vicinity range from 12 to 200 feet in depth. rock is struck about 150 feet from the surface, and is reported to a good supply of rather soft water, the water from the drift is hard. water rises in some of the deep within 3 feet of the surface.

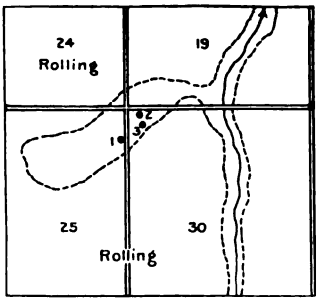


FIG. 30.—Sketch map showing valley in which flowing wells occur in Genesee and Richfield townships, Genesee County.

RICHFIELD AND GENESEE TOWNSH

Richfield Township, which is o eastern border of Genesee Coun rather strongly morainic or rollin is crossed by Flint River. The s is sandy along the river and throu central and northern sections. are very strong springs along the side of Flint River in sec. 1, one of w on the farm of R. J. Whaley, is carried by hydraulic rams t dwelling and barns. It issues from the bluff as a 4-inch st Wells were generally reported as shallow, and mostly of the ope type, although some are tubular. The depth was said to be 12 to 40 feet or more, with the supply and quality generally go

Flows occur in three isolated areas, as follows: A group of two on the farm of Peter Cimmerer on NW. ¼ sec. 30 (see fig. 30); a shallow well on the north side of sec. 28 on the farm of J. F. strong, near a spring in a pasture, and one on the north side of se belonging to Dr. J. F. Roemmer. None of these seem favorabl ated to make any marked extension of the present developmen sible. Those on Mr. Cimmerer's place are in a shallow valle necting with one of the tributaries of Flint River, and it is pro *that along the stream* other flows might be struck if wells we

ɔn near the bottom of the valley, but because of the slight head it robable that they could not be obtained on higher levels.

)ther probable places for flows were noted along the valley of Flint 'er, but as the houses are all on high ground above the river no ls have been sunk to test the matter. Leverett says: "On the th bluff just east of the county line a flow has been obtained at a el of 50 feet or more above the river."

n Genesee Township, which lies west of Richfield, one flowing well been obtained near the Cimmerer wells and in the same valley. s on the farm of C. and G. Galing in the NE. ¼ sec. 25. The drain- relations are shown in fig. 30.

There are a few deep tubular wells in this township which do not w. One on the farm of K. B. Todd, in sec. 11, on a plain about 60 t above Flint River, is 222 feet in depth, and strikes rock at 194 feet. e water, as reported by the owner, stands 50 feet below the surface, temperature is 50° F., and the water soft, with a trace of oil in it. ie rock resembles a grindstone in texture. The drift is largely a rd, stony clay. Mr. Todd furnished the following data concerning a ll at the schoolhouse in sec. 2 on the same plain. Rock was struck 175 feet, and the well carried to a depth of 194 feet. The water nds 33 feet below the surface, and its temperature is 50° F.

Wells of Richfield and Genesee townships.

Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Remarks.
					In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
8	7	25	C. and G. Galing..	1890	2	60	785	+3	0.5	51	Hard.....	Stock use.
8	8	30	P. Cimmerer.....	1896	1.5	65	788	+1.5	.75	51	Hard; iron	House well.
8	8	30	.....do.....	.....	1.5	60	785	+1.5	.5	.....	.....do....	Stock well.
8	8	28	J. F. Cartwright..	.....	1.5	20	800	.....	2	49	.....	In pasture.
8	8	34	Dr. J. F. Roemmer.	.....	1.5	50?	.....	.....	.....	.....	.....	

DAVISON AND BURTON TOWNSHIPS.

A flowing-well area lies in and about Davison village, in the north- n part of the township of Davison, extending southwest into Bur- n, the next township to the west. The area covers approximately square miles, 8 of which are in Davison. (See fig. 31.)

DAVISON.

Davison village and the flowing-well district about it is situated on plain which lies on the western or inner slope of the morainic ridge ning southwestward through the southeastern part of the county. rough the village a low, sandy spur runs nearly east and west, the of which is about 15 feet higher than the bottom of a shallow eam valley, along which most of the flowing wells occur.

The largest number of wells which flow is in Davison village, on the Grand Trunk Railroad, where about one-half of all those in the district are located. The whole number of wells recorded is 156. A few are no longer flowing, however, but were noted as indicating the possibilities of the locality for properly constructed wells.

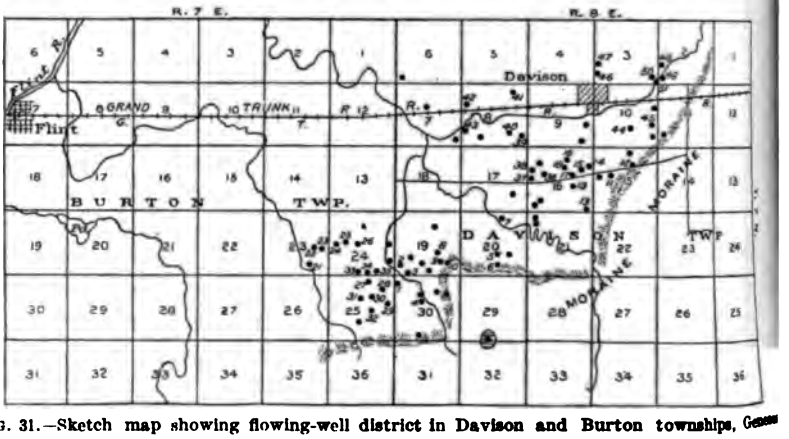


FIG. 31.—Sketch map showing flowing-well district in Davison and Burton townships, Genesee County.

The water comes from sand or gravel strata ranging from 20 to feet, and in one case (L. Raisin, No. 24) from 95 feet below the gene surface. A large percentage were reported as less than 40 feet de As in all districts where there are several water-bearing strata there much variation between the depths of adjacent wells, owing to irre

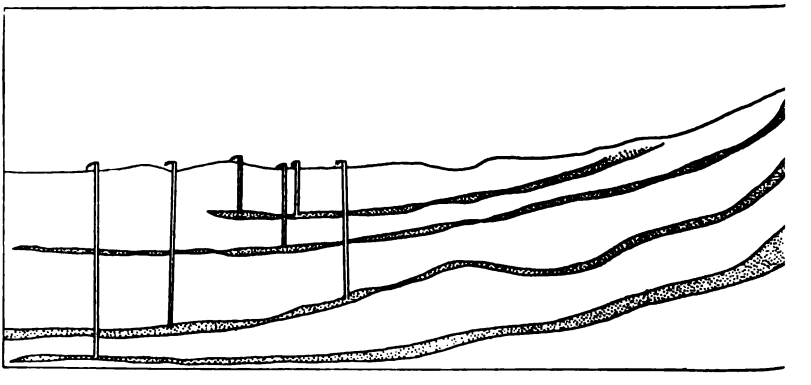


FIG. 32.—Diagram showing probable relationship of the water beds across secs. 10 and 11, Dav Township.

larity in the thickness of the strata, apparently in some such man as is shown in the ideal section (fig. 32).

This water is of about the same quality in all of the wells—rat hard with some iron present, but in other ways excellent. That fr the deeper wells seems rather less impregnated with mineral mat

than that from the shallower ones, but no accurate determination was made. The water should be healthful and as pure as ground water in this type of territory ever is.

A tough hardpan is reported as generally present over the water-bearing strata, which were said to be usually of fine sand for the upper and gravel for the deeper ones. Mr. A. Armstrong, however, reported

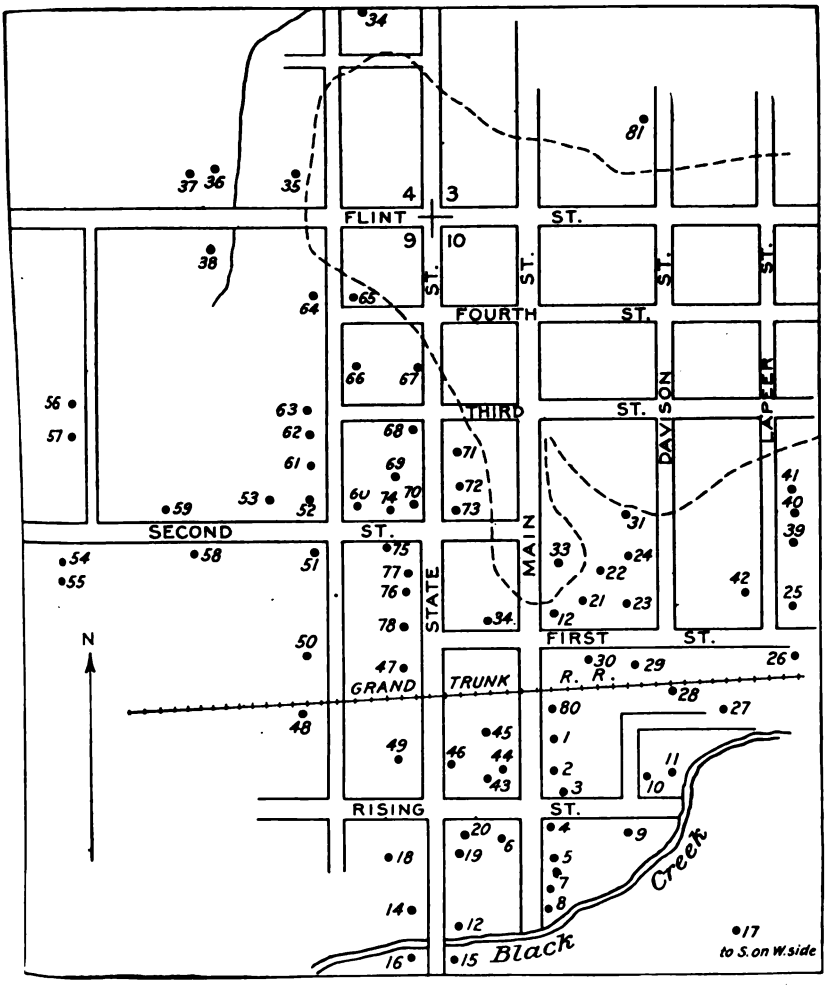


FIG. 33.—Plat showing distribution of flowing wells in Davison village, Genesee County.

that the well at the creamery, 66 feet deep, if shut off, always started roily, and when first put down discharged more than a wagon load of fine sand.

The wells in many instances were reported to be cased down into the clay for a few feet only, and but few of them had sand screens on the points.

The deeper wells have the greater head and the stronger flows, except a well near the stock yard of the railroad company, which was reported to be only about 16 feet deep and which flowed 10 gallons per minute at a height of 8 feet above the ground, quite equaling any other well visited. The well of Mr. L. Raisin when first put down was said to have flowed over the top of 32 feet of pipe, and while now reduced still has a strong head. One other well, that of J. F. Cartwright, the first to be put down to 70 feet, was reported to have a head of about 30 feet at first, but slowly fell as others were put down and is now below 8 feet. The 30-foot wells are all apparently of slight head and small flow.

At present the village has no public water system, and fire protection is obtained by allowing the water from some of the flowing wells to run into reservoirs. It is apparent, however, that it would be possible to get a good supply for public service by putting down a few wells in the lowest part of the valley to the depth of the lowest stratum, which, being least used, would give the best supply and would also interfere least with the existing wells.

The well of Mr. A. Tenney (No. 56) was on slightly higher ground than any other flow and proved to be a rock well 115 feet deep and said to be about 15 feet into the shale rock. In case this is a correct record, the 95-foot well of Mr. Raisin is probably in gravel lying on top of the rock.

Fig. 33 shows the location of wells in Davison village; the data are given in the following table:

Wells in Davison

No. on fig. 33.	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	°*F.*			
1	A. N. Trumbull	1904	2	72	$72	785	+10	8¼	50	Iron; lime.	Gravel	
2	A. J. S. Seeley	1904	2	75	78	785	+ 8	7		do	do	Slight flow because of No. 1.
3	do		1¼	30	30	785	+ 1	½	51	do	Sand	
4	do		1¼	30	30	784	+ 1½	½	51	do	do	
5	Mr. Uptograff		1¼	30	30	784	+ 1	½	51	do	do	
6	do		1¼		30	785	0	½	51	do	do	Flows at surface.
7	do		1¼		30	784	+ 1½	½	51	do	do	
8	do											Flows in cellar.
9	do		1¼		30	784	+ 2½	½	51	Iron; lime.	Sand	
10, 11	Brickyard		1¼		30	784	+ 1½	½	51	do	do	Used in boilers; does not scale badly.
12												No data.
13												Do.
14	G. Moore		1¼		30	782	+ 1	½				
15	G. Soper		1¼		307	782	+ 2	½	53			Formerly flowed more.
16	J. Reeser		2		20 or 30	788	+ 1	¼	52	Iron	Sand	Water not hard.
17	Chas. Hurd		2	95	94	790	+ 2	½			do	Flow has decreased.
18	Chas. Blackmore		1¼		30	785	+ 1	½	54	Iron; lime.	do	Flows in crock.
19, 20	do		1¼		30	785	+ 1					Flows in cellar.

Wells in Davison—Continued.

	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	°*F.*			
	J. J. Schweitzer		2		$70	787	− 6?	1		Iron; lime.	Gravel	In cellar.
	do		2		60	786	+ 2	1		do	do	At barn; flows on ground below well mouth.
	A. Bird											No data.
	L. Raisin		2	90	95	788	+32	4	49	Iron; lime.	Gravel	Flow controlled; said to have overflowed a 32-foot pipe at first.
	E. Pettis		1½	40	40	783	+ 1	½	50	do	Sand	Used for irrigating garden.
	Mrs. Yearns		1		20	780	+ 3	¾	49	Hard		Do.
	Storehouse of elevator company.		3		16	780	+ 7	10	50	do		Water mostly wasted.
	Grand Trunk R. R.		2		20?	780	+ 1					Not flowing now.
	do		2		40?	782	+ 3	¼		Hard; iron		Piped to town drinking fountain.
	Warehouse					785						Abandoned; clogged.
	Wm. Foote											No data.
	Davison House		2		73	785	+ 1	2		Hard; iron	Gravel	
	Store building				30 30	784 785	− 5 − 5					Both in basements.
	J. Smith		1½		32	786	+ 1½	½	50	Hard; iron	Sand	
	J. Taggart		1½		37	785	+ 1	1	50	do	do	Flows into tank.
	C. S. Lucas	1903	1½		70	783	+ 2	1	50	do		
	W. Shoemaker	1902	1½		50	785	+ 1½	½		do		Waste runs to village reservoir.
	M. Smith	1902	1½		40?	783	+ 1½	1½	50	do		
	H. Welsh	1902	1½		25?	785	+ 1	1	49	do		
	W. F. Burdick	1902	1½	25	27½	786	0	½				Lowered by No. 39.
	Mrs. Fenton		1½		27	786	0	½				Do.
	Frank Blackman		1½		18	785	+ 7½	¼	51		Gravel	Pioneer well; head +30 feet at first; piped to house.
	J. F. Cartwright		2	70	70	785	+ 8	2			do	
	do		1½		30	785	− 4	¼			Sand	In cellar; flow decreased.
	Cartwright (elevator).		1½		30	785	+ 2	½			do	
	Cartwright (old house well).		1½		30	785	+ 1	1/10				Just drops now.
	Sawmill		1½		30	786	+ 1½					Does not flow now.
	A. Armstrong	1891	2	66	66	786	+12	8	50	Soft	Sand and gravel.	Small flow at 30 feet; used in boiler and creamery.
	H. Newbaker			78	78	786	+12	8	50	do		
												No data.
	George Hill		1½		32	784	+ 2	½	50			
	Mrs. Cottrell		1½		30?	785	+ 1	½	50			
	H. C. Dayton		1½		104	787	+ 1					Small flow; pump well.
	J. Austen		2		92	794	+ 2	½	50			
	do		1		26	794	+ 1	½	51			Flows at bottom of tank.
	A. Tenney		2	115	115	804	+ ½	¾	50		Rock	Water slightly mineral; 15 feet in rock.
	Wm. Hall		1½		30	795						Intermittent.
	C. J. Adams	1904	2	65	93	789	+ ½	½	50.5	Hard		Water hardly rises above surface.
	Mr. Johnson	1902	2							Hard; iron		Incomplete.
	Mrs. Towar		1½		30	785	+ 3	½				Too hard for laundry.
	S. Lane		1½		360	785	+ 1	1	50			
	C. N. Sallick	1897	1½		40	785	+ 4			Hard; iron		In cellar.
	J. Hibbard				60	789	− 6					
	G. Haynes		2		35	786	+ 2	½	50	Hard; iron		
	L. Shales				(?)	789	+ ½	½		do		Flows in bottom of tank.
	Wm. Travis		1½		(?)	791	0	½				
	George Hall		2		60?	786	+ 3	½	50	Hard; iron		
	Barney Cole		1½		(?)	786	+ 3	½	50.2	do		
	L. Gifford		2		(?)	786	+ 3	½	53	do		Flows from pump.

Wells in Davison—Continued.

No. on fig. 33.	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	*°F.*			
70	C. A. Uptegraff					786	+ 3	1	50.2	Hard; iron		Piped to shop.
71	J. P. H. Bradshaw.		3		$62	785	+ 3	2	50.2	do		Lawn sprinkling.
72	Mr. Wagner					788	+ ½	½				Flows into crocks.
73	F. H. McGreggor		2		80	787	+ 3	2	50.2	Hard; iron		Do.
74	J. Deal		1½		25?	785	+ 1	½		do		
75	Mrs. Black		1½		60	785	+ 2	¾		do		Flow decreased.
76	J. F. Cartwright		2		70	785	+ 1	1	50	do		
77	Mr. Cummings		1¼		30	785	+ 1	¼		do		Loses largely by leaky casing.
78	D. Cobus	1876	1¼		30?	786	+ 1	¼		do		Gravel, 5 feet; hardpan, one-half foot; clay, 25 feet.
79, 80												In cellars; use discontinued; about 50 feet deep.
81	H. Southworth	1898	2		60	787	+ 4	1½	50	Hard; iron		

VICINITY OF DAVISON.

In the country district south and west of the village the wells were generally reported as bored by the owners and at most only a single length of pipe used for casing. This method of putting down makes the cost of construction very small, but it is not conducive to permanency. From the varying depths at which water was reported in this part of the area, it seems likely that the strata are not continuous with those of the village, nor is it probable that they are.

It seems probable that the rolling land east of the area serves as the catchment area and gives the head necessary to make the wells flow. The diagram, fig. 32, and the sketch map, fig. 31 (p. 162), show the supposed relation of the strata in vertical section, and the approximate position of the wells of the area to the rolling lands to the east.

In sec. 29, Davison Township, there is a single light flow in the bottom of a small marshy depression in the moraine. The marsh is but a few acres in extent and surrounded by hills. The well was remote from any house, and no data were obtained regarding it, but from the way it was constructed and its location it was evidently shallow. This was the only flowing well in the township found in the rolling country.

BURTON TOWNSHIP.

On the farm of A. C. Skinner, 3 miles southeast of Flint, in the NE. ¼ sec. 28, in the valley of Thread River, is a tile well 25 feet deep. The water flowed the year round until recently, when it was purposely shut off, and now in a wet season it rises 4½ feet above

surface and runs from the spout of the pump. The well is ıt 5 feet above the level of the water in the stream and 25 feet w the level at which any of the neighboring houses stand. This suggests the possibility of putting down other wells in the val- of the stream, with the reasonable expectation of getting flow- water from no great depth.

ı the central part of the township the wells are commonly shal- dug or bored 12 to 20 feet deep. One tile tubular well was ırted to be 50 feet deep, with a good supply of water. Doctor se's well, at the northwest corner of sec. 16, flows from the rock, ɔh is said to be 75 to 80 feet from the surface. Below 20 feet, l rock is reached, water is rather scarce in this part of the county. ı the southeastern part of the township, especially in secs. 23 24, water is abundant, and there are numerous flowing wells, ɔh form the eastern extension of the Davison area.

SUMMARY.

'he following table gives data of the wells in Davison and Burton ɪnships, exclusive of those in Davison village, which are given on ;es 164–166.

Wells in Davison and Burton townships.

Range E.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
				In.	*Ft.*	*Ft.*	*Ft.*	*Gls.*	°*F.*			
7 8	30	H. R. Thomas	1902	20	14	790	−5			Hard	Gravel	This well is in neighborhood of flows, but on higher ground.
7 8	19	Bert Thomas	1894	1½	25	782	+3	1	50.5	do	do	
7 8	19	E. Thomas		1½	30	785	+2	½	50	do	do	Has two wells.
7 8	30	A. A. Thomas		1½	30	780	+2	1		do	do	Well in pasture; another at house.
7 8	20	Fred Knapp	1884	1½	40	785	+2	1	50	do	do	Well in pasture.
7 8	20	do	1884	1½	40	780	+2	1½	50	do	do	Do.
7 8	20	F. Blackman	1898	1½	48	780		1				
7 8	19	Israel Hill		1½	50	780	0	½	50	Hard	Gravel	Water flows at surface; rock at 90 feet.
7 8	19	do		1½	50	780	+	½		do		Drilled well at bar, 111 feet deep, 16 feet in rock.
7 8	19	do		1½	60	780	+			do		
7 8	15	Oscar Harris	1894	1½	40	810	+3	½	54	do	Sand	
7 8	15	W. Walterhouse	1892	2	40	812	+3	½	52	do	do	Another well about the same on back of farm.
7 8	16	E. B. Terrill		2		808	+1	½			do	Water nearly soft.
7 8	16	Mrs. Wm. Fagin	1902	2	55	790	+2	1	50		do	Do.
7 8	16	do	1902	2	55	790	+1	3	50		do	Do.
7 8	16	do		1½	30	785	+2					Flow very small.
7 8	16	L. S. McAllister	1880	2	30	795	+ ½	½	50	Hard		
7 8	16	do		2	30	790	+3	1½	50	do		In hollow in field.
7 8	16	G. M. Gaylord		1½	30	790	+1½	½	50	do		In field.
7 8	30	Fred Blackmore				785						Bored well; small flow.
7 7	23	J. Phelps		2	20	770	+2	3	50	Hard		
7 7	23	R Van Tifflin [a]		2	15	775	+1½	1	50	do		Easy to get flows here anywhere at about 15 feet.

[a] Skellinger, a driller at Davison, states that the Van Tifflin wells are 30 to 40 feet deep. The spout has a head of 12 to 14 feet.

Wells in Davison and Burton townships—Continued.

No. on fig. 31.	Township N.	Range E.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gls.*	°*F.*			
23	7	7	23	R. Van Tifflin[a]		2	15	775	+1½	2	50	Hard		
24	7	7	24	do		2	15	775	+2	2	50	do		
25	7	7	24	do		2	15	775	+2	3				
26	7	7	24	do		2	15	775	+2	1				
27	7	7	25	H. A. Day										These and others in neighborhood said to be 25 to 35 feet deep. Flow varies from one-half gallon to 3 gallons. Mostly old wells.
28	7	7	25											
29	7	7	25											
30	7	7	25											
31	7	7	25											
32	7	7	25											
33	7	7	24	Chamberlin place			30	780	+1½	1½	50			Rather hard water.
34	7	7	24	Mrs. Clark Day		2	35?	780	+2	4	50			Do.
35	7	7	24	A. Burns			30	780	+2	1	50			
36	7	8	16	P. P. Hill			30	785	+2	½	50			
37	7	8	16	do			30	785	+2	6	50			
38	7	8	16	do			30	785	+2	1	50			
39	7	8	8	M. H. Flint			...	789	+1½	½	50			In stream valley.
40	7	8	8	do			...	789	+1½	½	50			In woods.
41	7	8	8	E. N. Demanois		2½	...	790	+1½	½	51			Water medium hard.
42	7	8	8	F. Hill	1898	2	114	785						Flowed 2 years, then stopped; water medium hard.
43	7	8	8	B. Cartwright		2		780	+2	2	50	Medium		
44	7	8	10	I. W. Cole		2	25	785	+2½	5	50	do		
45	7	8	10	do		1½	40	788	+2	1	50	do		
46	7	8	3	J. J. Worden		1½	40	790	+2½	½	50	do		In marshy pasture.
47	7	8	3	N. Haines		1½	40	790	+1	½	50	do		
48	7	8	2	W. Dillenbeck		1½	30	785	+2	½		Hard		In pasture.
49	7	8	2	do		2	60	785	+1½	½	50	do		
50	7	8	3	V. Henderson		2	50	785	+1½	½	50	do		
51	7	8	3	do		2	50	785	+2	½	50	do		

[a] W. Skellinger, a driller at Davison, states that the Van Tifflin wells are 30 to 40 feet deep. The strongest has a head of 12 to 14 feet.

GAINES AND MUNDY TOWNSHIPS.

SWARTZ CREEK.

The village of Swartz Creek is situated on the side of the ridge bordering the valley of the stream of the same name and is about 20 feet above it.

In the village the wells are said to be generally shallow—from 12 to 30 feet in depth—the water coming from below a thin layer of hardpan.

The well of Mr. William Clark, on the broad flat terrace of the stream, usually flows with a head of about 2 feet, but had just ceased when visited by the writer. The flow was said to be a small one. The well is about 25 feet deep.

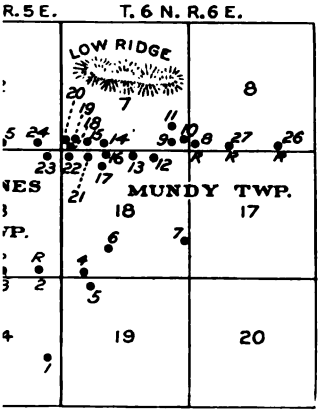
From this single well it seems likely that tubular wells put down in low places on the terrace of the creek would give flows, and especially so since the ridge bordering the valley gives a good catchment area and head.

GAINES AND MUNDY AREA.

area lies 2 to 3 miles south and from 1 to 2 miles east of Swartz
n a flat trough or plain, with a low ridge to the north. (See
)

ı rock and drift flows occur, but the drift or gravel flows
, as would be expected, much the smaller part of the area. No
ıt was made to get a full list of the flowing wells from the rock
e townships.

area where flowing wells occur covers only about 1 square mile
entirely without features, being so flat that little difference of
ın be seen over the whole of it. The wells are shallow, ranging
0 to 12 feet in depth at the western end of the area to 40 or even 80 feet in other parts, though most of them were reported as being about 25 feet deep. The water usually flows in sufficient quantity for the owners' needs, but a few wells had ceased flowing or had become so feeble that pumps were used. This seems to indicate that the catchment is small and local, being affected by the local weather conditions, the head of many of the wells being reported as less in the summer than in the winter.



Map showing flowing wells in the Gaines-Mundy area, Genesee County.

The water is medium hard, with a small quantity of iron present.
catchment area may be a low ridge to the north of the area
the larger number of wells are, or it might be any tributary higher
ear by, since the head is so low.

k wells are situated around the border of the area of drift wells.
ıck surface is reported to vary from about 100 feet in most of
lls to 180 feet in the well of Mr. J. H. Short, in which the rock
arkably deep considering the showing in the wells on either side.
ater is from sandstone, is fresh and sweet, is usually softer,
ss iron than the waters from the drift, and the supply is likely
more permanent because of the much greater area from which
ıter can come. The table on the next page gives data relating
s group of wells.

Wells in Gaines and Mundy area.

No. on fig. 34.	Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gal.*	°*F.*			
1	6	5	24	J. H. Short		1½	17	820?	+1½	5	50	Hard	Gravel	Bored in creek valley.
2	6	5	13	do	1903	2	280	830?	+1	½		Soft	Rock	Sandstone at 180 feet; cost, $168.
3	6	5	13	G. S. Eigentrager	1902	2	130	800	+2	1½	55.2	do	do	Water from top of sandstone.
4	6	6	18	A. D. Stevens	1896	2	132	830	+3	3	51	do	do	25 feet in sandstone.
5	6	6	19	R. N. Barlow	1897	2	130	835	0	3	51	do	do	15 feet in sandstone.
6	6	6	18	J. B. Coqingue		2	30	830	+2	½	51	Hard; iron	Gravel	Bored with auger; affected by drought.
7	6	6	18	J. D. Perry		1	37	835	+2	½		do	do	Very feeble flow; well near has ceased.
8	6	6	8	School district	1898	3	101	820	+3?	1	50.6	Soft	Rock?	Said to be just to rock.
9	6	6	7	L. Close		1½	25	820	+1½	½		Hard; iron	Gravel	Affected by seasons; used for cooling.
10	6	6	7	do		1½	25	820	+1			do	do	
11	6	6	7	do		1½	15	820	+2	1	50	do	do	Low ground in pasture.
12	6	6	18	L. Shelton		1½	40	820	−3			do		Small flow.
13	6	6	18	I. D. Gazley	1902	2	80	820	+2½	½	52	do	Gravel	Flow has decreased.
14	6	6	7	W. Beebe	1900	1½	25	820	+8	3	52	do	do	
15	6	6	7	C. W. Curtis		1½	29	820	+2	½	51	do	do	Flows.
16	6	6	18	Wm. Cummings		1½	30	818	+2	½		do	do	
17	6	6	18	do		2	25	818	+2	1	50	do	do	
18, 19, 20	6	6	7	J. D. Burnham										Three small flows; one pumped.
21	6	6	18	Mrs. C. Wood			25							Flows no more.
22	6	6	18	M. N. Wood			30							Do.
23	6	5	13	J. W. Wood		1½	20	816	+ ½	2½	49	Hard; iron	Gravel	Bored; flows in tub.
24	6	5	12	M. N. Wood		2	12	815	+2	5	50	do	do	On bank of ditch.
25	6	5	12	W. A. Stoner			10	813	+ ½	1				Crock well; overflows.
26	6	6	8	Chas. Allen	1903	2	100	820	+2	2	50	Soft	Rock	Well in sandstone.
27	6	6	8	W. S. Blass								do	do	Sandstone.

GAINES.

The wells at Gaines range from shallow dug ones to deep drilled ones—from 120 to 195 feet. Good supplies of water are found in sand and gravel below clay at from 20 to 175 feet. Rock has not been reached in any of the wells.

GRAND BLANC.

Grand Blanc village is located in a rolling district, and is perched on a low ridge overlooking the valley of Thread Creek. Wells on the ridge, to obtain permanent and sufficient supplies for ordinary use, have to be sunk into the rock (which is reported as being from 160 to 200 feet below the surface) to a total depth of 200 to 360 feet. Shallow wells vary from 25 to 70 feet deep, but usually do not give good supplies. The water rises in the deep wells to within 25 feet of the surface. On the edge of the valley on the east side of the town there

re some quite shallow wells. A well of Mr. M. Frazer, bored to a depth E 20 feet, has the water within 3 or 4 feet of the surface, rising from elow a thin bed of hardpan. The locality is a springy one, and nother well only 8 feet deep has the water nearly to the surface. The well on the place next south of Mr. Frazer's is said to be 56 feet eep, partly dug and partly bored, and the water rises to within 4 feet F the surface.

Springs are reported to occur along the edge of the valley on the orth side of the town.

In case the village ever attempts to incorporate a public system of ater supply the best place to make preliminary tests will be in the ottom of the creek valley at as low level as possible. The test wells ould determine the best location for a pumping station. In the valy the water would be more likely to be abundant, land would be heaper, and the chances of getting a flow either from the gravel or rom the rock are excellent. The water could be pumped to a standipe in the highest part of the town and good pressure thus assured.

ARGENTINE.

The wells in Argentine are from 15 to 30 feet deep, usually through . clay bed into water-bearing gravel.

FENTON TOWNSHIP.

LINDEN.

The village of Linden is situated in the valley of Shiawassee River, and gets a considerable part of its domestic supply from dug wells 20 to 35 feet deep. The drilled wells are from 75 to 175 feet deep, reaching rock about 100 feet from the surface. The quality of the water is good, though hard, as is usual in the region. That from the rock wells is reported as softer than that from the dug wells. The water in the rock wells rises to within 20 feet of the surface.

FENTON.

Fenton is built on the terraces of Shiawassee River, which has here cut a narrow valley in the bottom of a line of glacial drainage. The pumping station is on the bank of the stream at the lowest possible level, about 20 feet lower than the railroad station. The water is from a group of nine or ten flowing wells with slight head, ranging from 70 to 240 feet in depth, the majority of them being about 90 feet deep. The water flows into a brick reservoir of about 50,000 gallons capacity, from which it is pumped at the rate of 155,000 gallons in twenty-four hours, in spite of which fact there is a constant overflow into the stream. The pumps are connected with the stream in case of emergency, although the wells furnish 500,000 gallons a day.

The quality of the water is excellent, and seems less hard and has less iron than is usual in supplies of this sort.

The low bottom on which flows are obtained being subject to overflow, few if any dwellings have been built on it. For this reason the bottom has not been well tested for flows, but it seems probable that all along it flows might be obtained near the level of the river.

The larger number of these private wells were said to be of the shallow basin type, 12 to 40 feet deep. The water in those from the rock in the country around is said to be soft.

ATLAS TOWNSHIP.

ATLAS AREA.

These wells occur in the part of Atlas Township immediately adjacent to Oakland County on the slope of a stream valley about 5 miles south and west of Goodrich, just east and south of a low ridge. This flowing-well area is practically continuous with the Groveland area in Oakland County. The Atlas area is a small one, containing about 1 square mile, with six wells, one of which is from the rock. The drift wells are noticeably deep, and seem to come from near the top of the bed rock. The water probably rises out of the rock and accumulates under the overlying clay in a sand and gravel stratum lying on top of the rock.

There seems to be a locally developed shallow stratum, with slight head, in the eastern part of sec. 33, where two wells (one abandoned) of small flow from 20 feet down were reported.

Wells in Atlas area (T. 6 N., R. 8 E.).

No. on fig. 35.	Section.	Owner.	Cost.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
					In.	*Feet.*	*Feet.*	*Galls.*	° *F.*		
1	33	G. S. Horton	$95	1896	2	96	+15	8+	51	Medium; iron.	Gravel.
2	33	Drew Ries [a]	80	1892	2	78	+ 3	10	50	Hard	Sand, gravel.
3	33	James Ferguson	81	1893	2	81	+ 3	4	51	Iron; hard	Gravel.
4	33	Milo Van Tyne	91	1891	2	91	+ 1	3	51	do	Do.
5	34	C. Groves [b]			1	20	+ 2	2		do	Do.
6	33	J. P. Platt [c]	186	1892	2	186	+ 3			do	Sandstone.

[a] Piped to house, horse barn, and barnyard. Mr. Ries formerly had a well in the low part of his garden 20 feet deep, with a small flow of 2 feet head.
[b] Located in springy place in the woods.
[c] Flows just above the surface; piped to barn and flows there a ½-inch stream.

GOODRICH.

The village is situated in Atlas Township in a rolling district on the side of the valley of Hartley Creek, which is dammed at this point for power purposes.

The wells are said to be mainly shallow, from 20 to 30 feet deep. ey are dug or of the tile basin type, and have abundant hard water good quality.

There are several rock wells in and near the village in which, gener- y, the water rises within 8 to 15 feet of the surface. The water nes from a fine gray sandstone, and is of good quality, with some neral matter, mainly iron, in it. It is softer than the waters from gravel above the rock. Doctor Whelock's well is 171 feet deep, 40 50 feet into the rock, and the water stands 14 feet below the surface. e deepest rock wells are said to be over 200 feet.

The well at the schoolhouse, 235 feet deep, is 105 feet into the rock. lows 2½ gallons a minute, 2½ feet above the surface. The water has emperature of 51° F. as it flows from the pipe, is slightly saline, and considerable iron in it. The well was drilled about 1898, at a cost $91.

This well is on ground high enough to make it seem probable that d flows could be secured in other parts of the village by going down the same stratum.

The stream and pond at this place suggest the practicability of uring water for fire protection easily and cheaply, and eventually se sources of supply will probably be utilized for the purpose.

ATLAS-HADLEY AREA.

This area occupies a valley that lies between morainic ridges, and braces perhaps 10 square miles in the townships of Atlas (Genesee unty), Hadley (Lapeer County), and Brandon (Oakland County). e fig. 35.) The Ortonville and Brandon Township flows are near south end and are treated separately[a] because of their great devel- ment. From Ortonville the flows extend as far as Hadley, Lapeer unty, 7 miles to the northeast, appearing at frequent intervals ng the valley and the lower part of its slopes.

The area includes six or seven wells in Atlas Township, and at least ht in Hadley Township, and there may be some which escaped tice in both of these townships. The number in Brandon Town- ip, which should properly be included, is about 100.

It is probable that in many places in the lower parts of the valley ws could be obtained, but because of the undrained character of the l and the scattered population of the district there are relatively w houses at low enough levels to be within the limits of flow. The t that the porous gravels along the sides of the valley yield good pplies of water for shallow wells does away with the necessity of tting down deep ones. Along the road between secs. 15 and 16, adley Township, is the greatest development of any place in the

[a] See Water-Sup. and Irr. Paper No. 182, pp. 184-187.

area. Here the first well to flow was a dug well, in which, at the time of construction, in the early sixties, the water rose so rapidly that the bottom had to be choked with stones to enable the owner to have it walled up. This well is still flowing several gallons a minute into a tile drain.

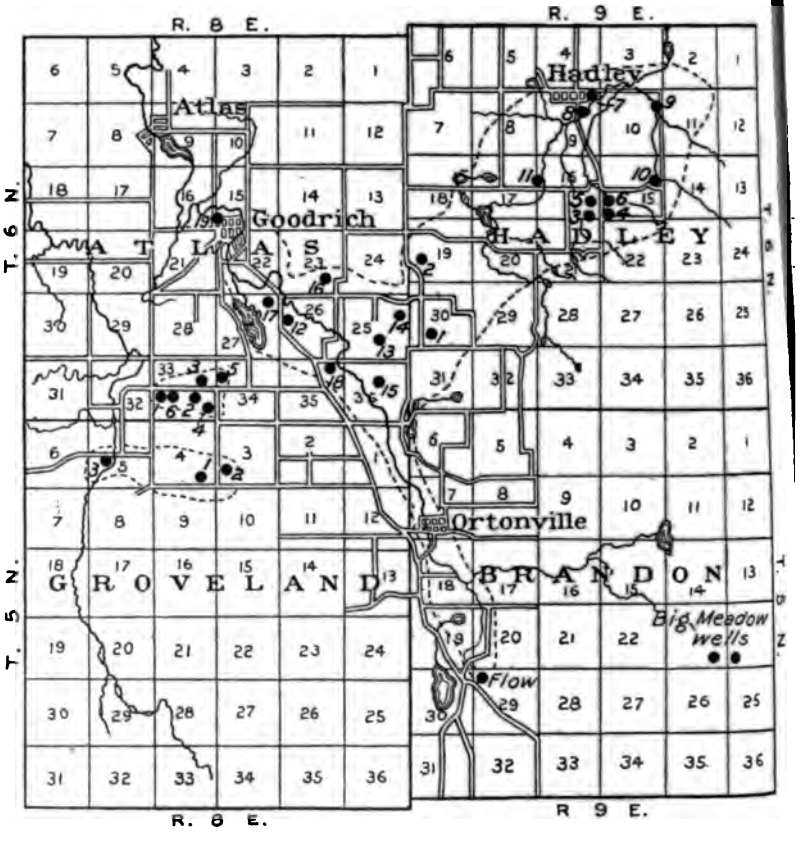


FIG. 35.—Sketch map of the Ortonville, Hadley-Atlas, Groveland, and Atlas flowing-well areas.

At Hadley, the well on the school grounds, 147 feet deep, is 14 feet into the rock, and flows just above the surface. North of Hadley no flowing wells were found. The well of Mrs. Jones, in the northern part of sec. 22, Hadley Township, was reported as 284 feet deep, with rock at 274 feet. It passed through 50 feet of till at the top, and white sand thence to the rock.

Wells in Atlas-Hadley area.

Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
					In.	*Ft.*	*Ft.*	*Ft.*	*Gal.*	*° F.*		
6	9	30	J. Toady	.....	2	80	950	+ 4	....	51	Hard; iron	Gravel.
6	9	19	C. Gregory [a]	.....	....	4	.....	+ 1	....	....	Iron.....	Do.
6	9	16	D. Riley [b]	.....	2	31	900	+ 1	....	51	Hard.....	Do.
6	9	15	C. S. Riley	.....	2	67	890	+10	3	51	.....do....	Do.
6	9	16	D. Riley [c]	.....	2	50	890	+ 1	....	52	.....do....	Do.
6	9	15	Silas Riley [d]	1864	....	38	895	.....	4	52	.....do....	Do.
6	9	9	Hadley school	1902	2	147	895	+ 1	1	51	Medium ..	Rock 14 ft
6	9	9	Hadley creamery [e]	1901	2	110	885	0	....	....	Hard; iron	
6	9	10	A. Eckers	1904	2	47	880	+ 5	2	50	.....do....	
6	9	15	Spring [f]	.....	1	5	875	+ 2	2	60	.....do....	
6	9	15	R. Hartwig [g]	.....	2	35	.....	− 4	1	....	.....do....	
6	8	26	Calvin Rhodes	.....	2	68	888	+ 1	2	50	.....do....	
6	8	25	J. R. Kipp [h]	.....	2	60	.....	.....	....	....	.....	
6	8	25	W. Armstrong [i]	.....	2	125	930	− 1	....	....	Hard.....	
6	8	36	Jas. Sheldon [j]	.....	2	165	910	+ 4	4	....	.....do....	
6	8	23	S. Spicer [k]	.....	2	131	.....	.....	....	....	.....	Sandstone
6	8	27	Mrs. Rhodes [l]	.....	2	133	.....	.....	....	....	.....	Do.
6	8	15	Goodrich school	.....	....	.....	.....	.....	....	....	.....	Rock.

[a] pring boxed in woods with spout to trough.
[b] lowed until within two months when it lowered 4 inches and is now pumped; flows at barn.
[c] Used to flow ½-inch stream; very small flow now.
[d] irst flow of the area; dug well; partially filled with stone to check overflow.
[e] ould flow at surface, but is pumped.
[f] rom a near-by spring; used for watering stock.
[g] umped at barn, but piped to stock trough on hillside and flows there.
[h] n pasture; piped to farmhouse.
[i] iped to barn, where it flows.
[j] and 55 feet, clay 10 feet, gravel with water at bottom.
[k] iped to barn, where it flows.
[l] lows at barn; water at 118 feet in gravel; best flow from rock.

WATER SUPPLIES OF LIVINGSTON COUNTY.

TOPOGRAPHY.

Livingston County, of which Howell is the county seat, is west of kland County. The interlobate morainic system which traverses kland County centrally from northeast to southwest passes across southeastern part, and Huron River traverses it in a southwesterly urse about on the line between the Saginaw and Huron-Erie por- ons of the interlobate system. There are numerous lakes along the er and in the moraines on either side. From this interlobate raine there is northwestward drainage to Cedar and Shiawassee ers. The former drains the western part of the county to Grand ver and thence to Lake Michigan, while the latter drains the north- n part of the county northward into Saginaw Bay. The north- stern part of the county is occupied by a much smoother tract an the southeastern, though feeble moraines are traceable, and ere are several gravel ridges or eskers which lead up into the erlobate moraine.

Wells are obtained throughout the county at moderate depths, ually without reaching the rock. A number of wells, however, in e northwestern portion have been sunk a short distance into the

rock, which is reached at about 100 feet. This part of the county is embraced in the discussion, by Doctor Lane, of the region around Lansing.[a]

SUPPLIES BY DISTRICTS.

HOWELL.

The town of Howell is situated on a gently undulating plain near the geographic center of Livingston County. To the south is a depressed area, in the bottom of which are marshes and several small lakes.

WATERWORKS.

Howell has a waterworks system, which obtains its supply from a group of ten 6-inch tubular drilled wells, located in a shallow drainage valley near the Pere Marquette Railroad station, in the western part of the town. These wells have been in use since 1894, and the water is said to come from gravel, lying at a depth of 65 feet below the surface, and to rise to within a foot of the surface when the pumps are not in operation. When pumped at the rate of 600 gallons a minute, the water is lowered 7 or 8 feet, but at the usual rate of pumping during the summer season (from 275,000 to 300,000 gallons in twenty-four hours) the lowering is only 4 feet. The supply was said to show some signs of failure, but this is attributed to the tendency of the strainers to become clogged, as all the wells show this tendency after a few months of use, and unless the wells are frequently sand pumped the supply is reduced. The supply is, however, adequate for all the present demands, and the water is of good quality, though hard and containing some iron. It is used for fire protection, lawn sprinkling, for boilers, and for general domestic purposes.

(1) There are many shallow dug wells in Howell, which are used commonly as sources of drinking water and as domestic supply. The depth of these wells ranges from 15 to 50 feet and the water is generally less hard than that of the city supply described above.

FLOWING WELLS.

In the southeastern part of the town, in one of the areas of marsh land mentioned above, is a group of flowing wells (see fig. 36) of slight head and generally small flow, which forms the largest group of this type in the county.

From their situation in relation to the higher lands around it is difficult to determine whether the sources of supply for this area are in the morainal hills and sandy slopes to the south or in the long, rather sandy slope to the north, as either or both might contribute water. The small flows and slight head would indicate, however, that there is

[a] See Water-Sup. and Irr. Paper No. 182, pp. 170-175.

er a small catchment area or one in which the porosity is too slight ield any considerable amount of free water. The general con- ration of the locality and direction of drainage seems to favor a hment area to the south, where the area of porous soils is more ted than to the north.

he obtainable records of wells put down in this locality indicate there are two water-bearing strata generally available. The er, of about 1 foot in thickness, is a coarse sandy gravel, which ls a good supply of water at depths varying from 6 to 12 feet. is usually capped by a clay bed, and the water has sufficient head ive slight flows at or slightly above the surface. The usual prac- is to shut off this vein and go down to the lower one, a wise

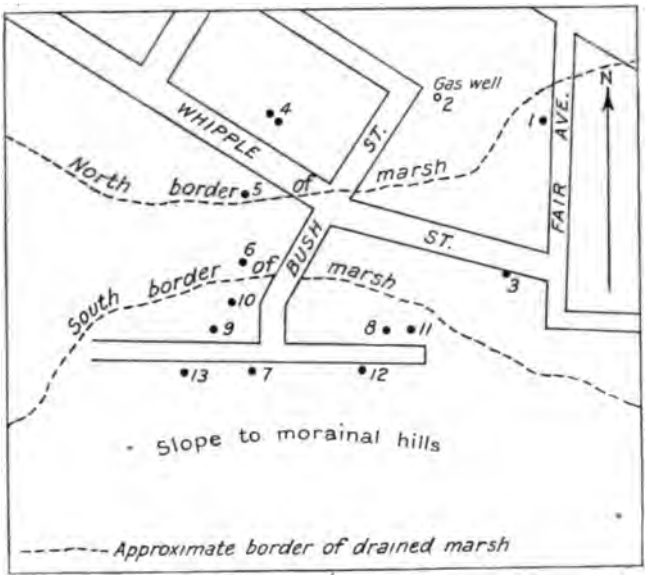


FIG. 36.—Plat of portion of Howell, Livingston County, showing flowing-well district.

tice, since there is no general sewer system, and the chances of amination from cesspools, etc., are considerable under existing litions. The only wells obtaining their supply from this vein those of Mr. Charles Arnold and his neighbor across the street.

he lower water-bearing stratum is from 40 to 60 feet below the sur- and is of unknown thickness. It is covered by a thick bed of blue so free from stones as to be easily bored through with the small er commonly used in sinking the wells, and so compact that usually asing is used, except enough to shut off the water from the upper . In most of the wells this water-bearing gravel is said to be te, rather coarse, and free from sand. The water is hard, with siderable iron in it.

The valley extends east, west, and southwest, but at present is not inhabited, because of its marshy character. Wherever the surface is sufficiently low the conditions would seem to be favorable for finding flows, either from the stratum from which the present supply is obtained or at a greater depth; and as the marshy area becomes settled the present area of flows may be extended.

The only other flowing well near Howell is that on the farm of E. P. Gregory, in sec. 2, Marion Township. This is a bored well, said by Mr. Gregory to be 34 feet deep, but by the driller, Mr. Andrew Feeley, from memory, to have the following record:

Records of E. P. Gregory's well, Marion Township.

DRILLER'S RECORD.	Total (feet).	MR. GREGORY'S RECORD.	Total (feet).
Sand	12	Sand and gravel	7
Clay, very stony	57	Tough blue clay	33
Clay	67	Water gravel; strong flow	34
Water gravel; streng flow.			

This well is situated 20 feet above and 60 rods north of Shiawassee River on the slope of a well-marked drift ridge. The head is about 7 feet, and the flow, as arranged at present, is about 12 gallons a minute. The water is hard and with considerable iron, but of excellent quality. It is used to cool milk, to water stock, and for all domestic purposes.

From the situation of this well, so much above the stream level, it is probable that the side of the valley farther down the slope would yield flows, but there are few residences in the neighborhood, and these are all on higher ground, while the pastures bordering the stream are sufficiently watered to make the sinking of wells unnecessary.

Mr. W. S. Papworth, in putting down a well some sixteen or eighteen years ago, struck a small flow of gas in the sand under the upper clay. When first struck, the gas was said to burn at the mouth of the pipe with a flame "as large as a barrel." The gas was piped to the house and supplied a single burner for six months with sufficient gas to give a constant bright flame. The sand constantly clogged the well so that the water could not be pumped, and the well was finally abandoned and filled up. The gas was in all probability "marsh gas," which in some way had accumulated in the sand as the result of decaying vegetation in the neighboring marshy area.

Wells at Howell.

Owner.	When made.	Diameter.	Cost.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Water bed.
		In.		*Feet.*	*Feet*	*Feet.*	*Gals.*	*° F.*	
apworth [a]	1897	2	$12	55	910	+3	0.5	51	Gravel.
apworth [b]	1888	1	5	20	915	−3	.....	.....	
eley [c]	1896	2	4	45	905	+5	1.5	49.2	Do.
rnold [d]	1895	2	2	12	915	+ .5	1	50.5	Coarse gravel.
uncan [e]	1897	2	.....	35	909	+1.5	1	51	Gravel.
arrett [f]	1900	1	3	37	912	+1.5	.5	50	Do.
ischke [g]	1899	1	3	35	912	.....	1	.....	Do.
Tilden	1901	1	4	42	914	+ .5	1.5	49.5	Do.
idall [h]	.....	1	4	40	913	+2	1	50	Do.
usten [i]	.....	2	.....	40	910	+2	2.5?	52	
Perry [j]	1900	1	4	44	914	0	1	50	Do.
nett	.....	1	4	42	910	+2	1	51	Do.
er	.....	1	.....	40	912	+1	.....	.....	Do.

e feet blue clay; 20 feet of casing.
ed gas for a year, then filled with sand.
'eet; sand, 15 feet; blue clay, 20 feet; reddish hardpan, 5 feet; water gravel at bottom.
now flows in basin; used to flow above surface; pumped now. Sand, 6 feet; clay, 5 feet;
t. Mr. Arnold has two similar wells.
cted by pumping Arnold's well across street. Sand, 8 feet; clay, 26 or 27 feet.
am, 2 feet; clay, 35 feet.
p, but would flow if owner cut down to head and deepened slightly.
andy soil 4 feet; clay, 6 feet; gravel with water, 1 foot; blue clay to 40 feet. The lower gravel
ite, and has little sand; more than 4 feet thick.
' in group, but runs into tank.
ist below surface; flows into basin.

llowing are partial analyses of the public supply and a shallow Iowell. The city water has to be mixed with rain water from for use for laundry purposes. The data were furnished by ighton, of the United States Geological Survey.

Partial analyses of well waters at Howell.

[Parts per million.]

	1.	2.
.....	51	65
.....	2	2
.....	11	27.6
ide (CO_3)	89.39	139.96
xide (SO_3)	10	51
s $CaCO_3$)	+139	322

, analyst. 1. William Barrett; depth, 38 feet; water at 15 feet. 2. City; depth, 68 feet.

PINCKNEY AREA.

rea consists of a group of three wells in a shallow valley 1½ st and 2 miles north of the village of Pinckney.

wells are about 60 feet deep, and flow 2 or 3 gallons a minute, ove the surface.

xplorations were known to have been made to determine this area can be extended, but it seems probable that it could e east, toward Hay Creek.

COHOCTAH AREA.

Cohoctah Center is a small village located on one of the branc Shiawassee River. The houses generally stand on a sandy te 10 or 15 feet above the level of the stream, and water is obtained shallow dug wells.

Near the stream level are three tubular wells which flow (fig but the quantity is small an head slight, so that at one basin has been built into the water flows and anothe been fitted with a pump. cost of one of these wells (was but $4.50. The indic are in favor of a possible g development along the vall the stream if conditions s arise making this desirable. also quite probable that d wells would give larger flows with greater head. These wells bored with an auger. The accompanying table gives the sta of these wells and fig. 37 shows their approximate location:

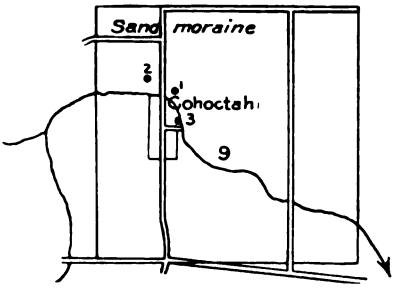


FIG. 37.—Sketch map of Cohoctah flowing-well area, Livingston County.

Wells in Cohoctah area.

No. on fig. 37.	Owner.	When made.	Diameter.	Depth.	Elevation of well.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quali
			In.	*Ft.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	J. S. Gordon	.....	1.5	33	915	882	+2	.5	49	.....	Hard, wit iron. well.
2	.....	1903	1.25	31	918	887	+ .5	.5	49	Sand	Hard; son
3	J. Trowbridge [a]	1892-3	2	49	918	868	0	.....	....	Gravel	Hard.

[a] This well had just ceased flowing. Said to flow during the wet part of the year over the end which is cut off near the surface of ground.

Cohoctah station is situated on the Ann Arbor Railroad, abo level of the old village. It has shallow dug wells from 23 to 67 f depth, the usual depth being about 50 feet. The water in them from a gravel bed to within 18 to 23 feet of the surface. The wa hard and has considerable iron in it.

DEERFIELD.

About 2½ miles east and 1 mile north of Oak Grove, on the side of sec. 29, Deerfield Township, is the sawmill and cider n Wm. H. Wenk. This is placed on the edge of the terrace of a sw

lley running off to the north, and at the foot of the terrace, in the ler room of the mill, is a well 72 feet deep, which, if it were not shut would flow the full size of the pipe. The water comes from a tum of sandy gravel 11 feet thick, and has a head of 16 feet. It s put down in 1896 by the owner, who furnished the following ord:

Record of Wenk flowing well, near Oak Grove.

	Thickness.	Total.
	Feet.	*Feet.*
and gravel	6	6
clay	64	70
pan	2	72
gravel with sand	11	83
pan.		

The pipe was drawn back to the top of the water-bearing stratum. e water was not hard, and had a temperature of 51° F. A bored ll at the house of Mr. Wenk, across the road, showed nearly the me section, except that there were 22 feet of sand before the gravel s reached. This well is on high ground, and the water rises in it thin about 7 feet of the surface.

It is quite probable that other flows might be obtained along the des of the valley to the north by going down to the level reached by he Wenk well. With the large head and thick water-bearing stratum here should be abundant water with which to use a hydraulic ram or vater motor for elevating water thus found to buildings at higher evels, but as yet, so far as learned, no other attempt than Mr. Venk's has been made to strike a flow in this vicinity.

HARTLAND AREA.

Beginning a short distance west and south of Hartland post-office nd extending northward along a swampy valley drained by one of the ninor branches of Shiawassee River are four or five flowing wells. The limits of the area are as yet undetermined, because of the sparse opulation and the general location of the houses and farm buildings pon the higher ground, but it is probable that flows would be struck n both directions along the valley beyond the present wells. The lows are from tubular wells, are rather weak, with slight head, and resent no phases of general interest. Their approximate location, nd the area of the basin, as at present developed, is shown in fig. 38.

On the farm of J. B. Crause, sec. 17, T. 3 N., R. 6 E., Hartland Township, about a half mile west of Hartland post-office, is a remarkable spring, really a natural artesian well, although now given an improved outlet by the owner. It is located near to and east of the house and 12 or 15 rods south of the road, below the edge of the highest terrace of a marshy valley. The natural outlet of the spring has been

dug out to a depth of 11 feet, down to the water-bearing stratum of fine gravel, and walled up with stone laid in cement, to a height of about 6 feet above the surface. The water rises to the top of this cistern and flows out in three streams; one, a waste pipe 1 inch in diameter, is allowed to run full into a ditch to the stream valley. A second pipe 1½ inches in diameter runs into a cooling tank in the milk house, and a third pipe runs a hydraulic ram which pumps water to the house and barns. The waste water from the milk house runs through a series of watering troughs in the barnyard before it is allowed to go to waste. Besides these outlets, a considerable quantity of water runs off through cracks in the cement and stonework near the top of the cistern. The entire outflow from this spring can not be much less than 20 gallons a minute, as the quantity received in the milk house is about 8 gallons. While the improvements were being made on the natural spring the water was carried off at a low level by ditch. Simultaneously some of the wells to the northwest are reported to have stopped flowing, thus suggesting an underground connection with the wells.

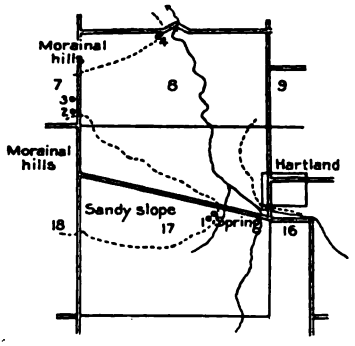


FIG. 38.—Sketch map of Hartland area, Livingston County, showing locations of wells.

Wells of Hartland area.

No. on fig. 38.	Owner.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		Inches.	*Feet.*	*Feet.*	*Galls.*	°*F.*		
1	J. B. Crause	1	15	+1.5	1	49.2	Hard, with some iron	Gravel.
2	C. Parsons	2	50	+2	1	50	do	Do.
3	A. M. Townley	2	62	+3	1.5	50	do	
4	Wm. Cullins	2	30	+3	1		do	Do.
5	J. B. Crause (spring)	48	11	+6	20	50	do	Do.

Below is given a partial analysis of the water from the Lockwood Hotel, at Fowlerville. It seems to be very highly contaminated from seepage from the livery stable across the road. It is probable that the typhoid, which has been prevalent in the town is due to the polluted supplies from wells of this sort. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Fowlerville.

	Parts per million.
Color	46
Iron (Fe)	.5
Chlorine (Cl)	57.2
Carbon dioxide (CO_2)	137.58
Sulphur trioxide (SO_3)	55
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth 40 feet.

WATER SUPPLIES OF SHIAWASSEE COUNTY.

TOPOGRAPHY.

hiawassee County lies west of Genesee County, and is traversed :he same system of moraines noted in the discussion of that county. ; northern edge was occupied by the Glacial Lake Saginaw. The nty is generally either plain or gently undulating. Between the raines are large valleys which represent lines of glacial drainage ling westward to Grand River. One of them, which passes just th of Durand and south of Corunna and Owosso, is known as the lay outlet and carried the waters of the large Glacial Lake Mau- e. The southwestern part of the county is now tributary to Grand rer, but the remainder drains northward through Shiawassee River l tributaries of Flint River to Saginaw Bay. The southwestern t of the county is discussed by Doctor Lane in his report on the ion about Lansing.[a]

SUPPLIES BY DISTRICTS.

OWOSSO.

FLOWING WELLS.

The Owosso flowing wells form the most important group in Shia- ssee County. They are located in and near a subdivision of the y known as Maple Ridge, which lies on a slightly sloping terrace the valley now occupied by Shiawassee River and south of the eam. It is a short distance north of a morainal ridge, which seems be the catchment area for the wells, and which here runs nearly st and west for some distance.

The wells are in three groups; the larger one in Maple Ridge Park per (see fig. 39) has about 25 wells, including those which uld flow above or at the surface if not pumped, while the smaller e, five blocks west and one south, has only six wells. What is nsidered by the writer to be a third group in this area occurs still ther southwest near the south end of South Chipman street, ere a single flowing well (No. 15 in table) and two pump wells ich would flow occur in the same neighborhood and have the same aracteristics.

The water in each group comes from a gravel stratum 18 to 25 feet low the generally even land surface, the cover being a compact clay l. The water is moderately hard and is somewhat impregnated th iron, and judging from the analysis of the sample from the neral spring given below, has a considerable amount of magnesium lts as well.

[a] Water-Sup. and Irr. Paper No. 182, pp. 170-175.

dug out to a depth of 11 feet, down to the water-bearing stratum of fine gravel, and walled up with stone laid in cement, to a height of about 6 feet above the surface. The water rises to the top of this cistern and flows out in three streams; one, a waste pipe 1 inch in diameter, is allowed to run full into a ditch to the stream valley. A second pipe 1½ inches in diameter runs into a cooling tank in the milk house, and a third pipe runs a hydraulic ram which pumps water to the house and barns. The waste water from the milk house runs through a series of watering troughs in the barnyard before it is allowed to go to waste. Besides these outlets, a considerable quantity of water runs off through cracks in the cement and stonework near the top of the cistern. The entire outflow from this spring can not be much less than 20 gallons a minute, as the quantity received in the milk house is about 8 gallons. While the improvements were being made on the natural spring the water was carried off at a low level by ditch. Simultaneously some of the wells to the northwest are reported to have stopped flowing, thus suggesting an underground connection with the wells.

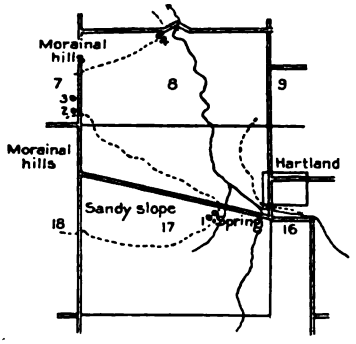


FIG. 38.—Sketch map of Hartland area, Livingston County, showing locations of wells.

Wells of Hartland area.

No. on fig. 38.	Owner.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		Inches.	*Feet.*	*Feet.*	*Galls.*	°*F.*		
1	J. B. Crause	1	15	+1.5	1	49.2	Hard, with some iron	Gravel.
2	C. Parsons	2	50	+2	1	50	do	Do.
3	A. M. Townley	2	62	+3	1.5	50	do	
4	Wm. Cullins	2	30	+3	1		do	Do.
5	J. B. Crause (spring)	48	11	+6	20	50	do	Do.

Below is given a partial analysis of the water from the Lockwood Hotel, at Fowlerville. It seems to be very highly contaminated from seepage from the livery stable across the road. It is probable that the typhoid, which has been prevalent in the town is due to the polluted supplies from wells of this sort. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Fowlerville.

	Parts per million.
Color	46
Iron (Fe)	.5
Chlorine (Cl)	57.2
Carbon dioxide (CO_2)	137.58
Sulphur trioxide (SO_3)	55
Hardness (as $CaCO_3$)	139 +

S. J. Lewis, analyst. Depth, 40 feet.

WATER SUPPLIES OF SHIAWASSEE COUNTY.

TOPOGRAPHY.

Shiawassee County lies west of Genesee County, and is traversed r the same system of moraines noted in the discussion of that county. he northern edge was occupied by the Glacial Lake Saginaw. The unty is generally either plain or gently undulating. Between the oraines are large valleys which represent lines of glacial drainage ading westward to Grand River. One of them, which passes just orth of Durand and south of Corunna and Owosso, is known as the mlay outlet and carried the waters of the large Glacial Lake Mauee. The southwestern part of the county is now tributary to Grand iver, but the remainder drains northward through Shiawassee River nd tributaries of Flint River to Saginaw Bay. The southwestern art of the county is discussed by Doctor Lane in his report on the egion about Lansing.[a]

SUPPLIES BY DISTRICTS.

OWOSSO.

FLOWING WELLS.

The Owosso flowing wells form the most important group in Shiawassee County. They are located in and near a subdivision of the city known as Maple Ridge, which lies on a slightly sloping terrace in the valley now occupied by Shiawassee River and south of the stream. It is a short distance north of a morainal ridge, which seems to be the catchment area for the wells, and which here runs nearly east and west for some distance.

The wells are in three groups; the larger one in Maple Ridge Park proper (see fig. 39) has about 25 wells, including those which would flow above or at the surface if not pumped, while the smaller one, five blocks west and one south, has only six wells. What is considered by the writer to be a third group in this area occurs still farther southwest near the south end of South Chipman street, where a single flowing well (No. 15 in table) and two pump wells which would flow occur in the same neighborhood and have the same characteristics.

The water in each group comes from a gravel stratum 18 to 25 feet below the generally even land surface, the cover being a compact clay till. The water is moderately hard and is somewhat impregnated with iron, and judging from the analysis of the sample from the mineral spring given below, has a considerable amount of magnesium salts as well.

[a] Water-Sup. and Irr. Paper No. 182, pp. 170–175.

The water in the wells on the highest part of the Maple Ridge district rises not more than 8 feet above the lowest part of the district, which is a shallow drainage valley. A well (No. 1) recently put down in this lowest part has, because of faulty construction, allowed the water to rise around the casing and run to waste in large quantities. Coincident with this large waste several wells at higher levels have lost head and either decreased in flow or ceased flowing altogether.

Some of the wells are on property which has frequently changed hands, and it was not possible to secure data regarding them. How-

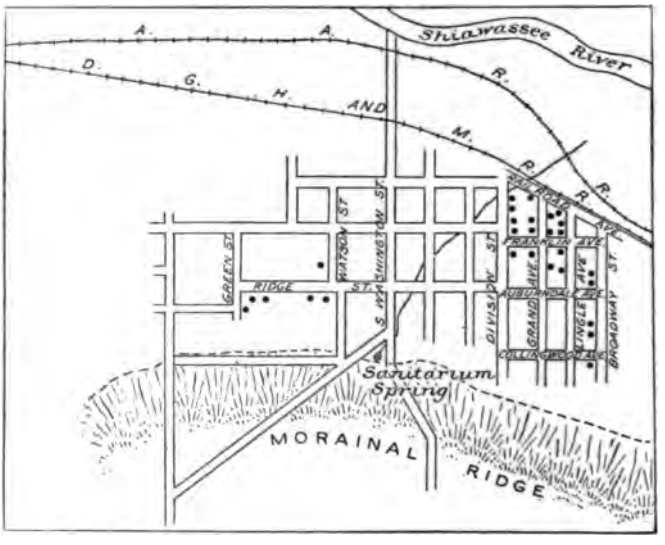


FIG. 39.—Sketch map of Maple Ridge Park and vicinity, Owosso, showing approximate locations of flowing wells.

ever, statistics relating to those of most interest, sufficient to show the characteristics of the area, are given in the accompanying table; the relation of the area to the river and moraine is shown in fig. 39.

The districts between these groups are not yet built up, and it seems probable that when they are the number of flows will be increased by new wells in the intermediate spaces unless the water is lowered so far by that time as to fail to give flows. This area should furnish a very constant and good supply of water for household use from tubular pump wells, at small expense, even where flows can not be obtained.

Wells at Owosso.

Owner.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
	In.	*Feet.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			
.A. Armstrong..	1.5	20	753	+2	2.5	50	Hard; iron	Gravel..	Lowest in the series.
...do.....	1.25	26	760	+1.5	1-2	49.2	.....do....	....do...	
...do.....	1.25	26	760	+1.5	1	.....	.....do....	....do...	6 feet from No. 2.
'.J. McDavid....	1.25	25	760	+2.5	2	50	.....do....	....do...	A second well used to flow.
..A. Hamblin....	1.25	20±	762	+ .5	.....	.....	.....do....	....do...	Pumped to avoid sewer connections.
)r. Sutherland...	1.25	20±	765	+2	2	49	.....	....do...	Water not very hard.
.. V. Leonardson.	1.25	20±	765	+2	1.5	49.5	Hard; iron	....do...	Used to flow; now pumped.
'aldwin estate...	1.5	25	765	+ .5	.....	.....	.....do....	....do...	Now pumped.
...do.....	1.5	28±	766	+0	1	.....	.....do....	....do...	
...do.....	1.5	25±	767	+ .5	.....	49.5	.....do....	....do...	Just drops from pipe.
...do.....	1.5	100±	765	+ .5	2	49.5	.....do....	....do...	
...do.....	1.5	18-20	765	+0	.25	49	.....do....	....do...	Lowered by No. 1.
.. B. Pulver.....	1.25	20±	766	+1	2	47.4	.....do....	....do...	Flows more after heavy and prolonged rains; 1884.
;. S. Kinney [a]....	1.5	20±	765	+1.5	1	49	.....do....	....do...	Flow varies with seasons; water medium hard.
). D. Rust.....	1.5	25±	768	+1.8	32	50	.....do....	....do...	Westernmost flowing well in district.

ing to change of owners no data could be had concerning four other wells in this group, but they aid to be of about the same depth as the others. The flows are small.

ıe following is a partial record from a very shallow but good flow-well at Owosso, owned by Charles Terry. The data were fur-ed by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Owosso.

	Parts per million.
.....	51
Fe).....	1
ine (Cl).....	1.5
›n dioxide (CO_2).....	121.36
ıur trioxide (SO_3).....	56
ness (as $CaCO_3$).....	139+

J. Lewis, analyst. Depth, 16 feet.

SPRINGS.

ssociated with this area are two large springs, which may come ı the same source. One is situated at the foot of the sharp slope he moraine on South Washington street and is covered by a sani-ım and bath house, now closed, which were erected to utilize its ers as a remedial agent. The spring is a large one, issuing from an ficial basin in the basement of the cellar in several streams in such ay that it is hard to determine its amount; but the waste water lly runs off in a surface stream more than 2 feet wide and 6 or 8 ıes deep. This spring water was for a time bottled and sold by the osso Sanitarium and Mineral Bath Company, but the enterprise abandoned, *and at present this* large supply is entirely running to

waste. The temperature of the water as it issues from the spring is 50° F.

A second large spring occurs at the foot of the same moraine about a mile farther east and is utilized by the city as a source of supply to supplement that obtained from the wells at the pumping station. The water from the spring is pumped to the large receiving well at the station and furnishes no insignificant part of the supply.

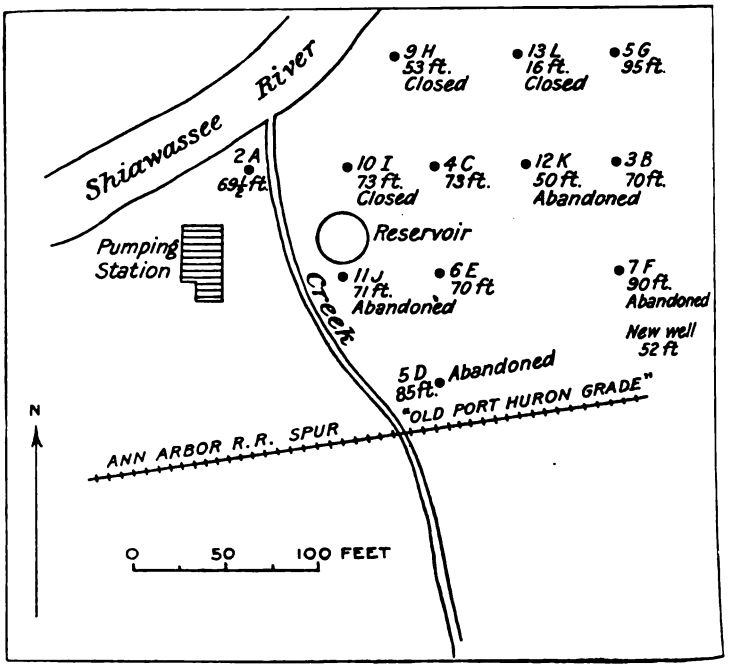


FIG. 40.—Distribution of wells at Owosso waterworks, on a terrace of Shiawassee River, 5 feet abo low-water level.

WATERWORKS.

The records of the Owosso waterworks wells are of interest in sho ing the variations in depth, character, and thickness of the drift b within a very limited area, and are therefore presented in full. F 40 shows their relative positions.

Driller's record of Owosso salt well (waterworks well No. 1).

	Thickness.	Tot
	Feet.	*Fe*
Muck	3	
Gravelly clay	32	
Gravelly mixture	10	
Gravel	6	
Clay	2	
Quicksand	7	
Coarse gravel	6	
Quicksand	19	
Blue clay	125	
Sand rock	30	
Salt water which flowed.		

well is located on the south side of the Ann Arbor Railroad bout 200 feet west of the east line of the corporation of the city, ›w lands owned by J. L. Wright. It is 240 feet deep, cased first 85 feet with 5⅝-inch tubing. At the depth of 85 feet e clay was reached, continuing down to the sand rock, which ck at a depth of 210 feet. Drilling was continued into the epth of 30 feet and there water was reached, which flowed at of 4 or 5 feet above the surface. The water was salt and ity was abandoned, the drill being moved 150 feet northward ward across the track."[a]

Driller's record of waterworks well No. 2.

	Thickness.	Total.
	Feet.	*Feet.*
.....	2	2
.....	5	7
.....	15	22
.....	5	27
.....	3	30
.....	3	33
.....	2	35
i.....	5	40
.....	6	46
.....	6	52
.....	16	68
vater flow.....	1.5	69.5

vell was pumped 60 gallons a minute for eighty consecutive The first few strokes of the pump lowered the water 12 feet, ich it did not lower it below 14 feet. The well is cased with ;ubing.

Driller's record of waterworks well No. 3.

	Thickness.	Total.
	Feet.	*Feet.*
.....	7	7
.....	5	12
.....	1	13
.....	14	27
.....	15	42
.....	1	43
ı water).....	12	55
.....	13	68
flow.....	3	71

'ell is 71 feet deep and is located 200 feet east of well No. 2 on › line.

[a] Record in waterworks office.

Driller's record of waterworks well No. 4.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	3	3
Gravel	6	9
Clay	9	18
Quicksand	16	34
Clay	6	40
Gravel and flowing water, with strong smell of gas at 43 feet	13	53
Quicksand	13	66
Gravel	7	73
Water gravel.		

This well is 100 feet west of No. 3.

Driller's record of waterworks well No. 5.

	Thickness.	Total.
	Feet.	*Feet.*
Soft clay	3	3
Quagmire	6	9
Gravel	23	32
Quicksand	6	38
Clay	5	43
Gravel with flow	5	48
Clay	6	54
Quicksand	3	57
Clay	4	61
Quicksand	11	72
Gravel with flow	13	85

This well is 85 feet deep and is located 120 feet south of No. 4. "This well does not flow as strongly as the other wells do. There are large quantities of coarse sand mixed with the gravel, presumably keeping the water back."[a]

Driller's record of waterworks well No. 6.

	Thickness.	Total.
	Feet.	*Feet.*
Muck	4	4
Gravel	3	7
Clay	11	18
Gravel	8	26
Clay	13	39
Gravel with flow	2	41
Quicksand	16	57
Coarse sand	10	67
Gravel with flow	4	71

"This is the best well obtained as yet."[a]

[a] Record in waterworks office.

Driller's record of waterworks well No. 7.

	Thickness.	Total.
	Feet.	*Feet.*
.....	22	22
.....	17	39
.....	4	43
low.....	11	54
.....	13	67
.....	3	70
.....	15	85
.....	5	90

ell is 100 feet east of No. 6. "This well is a failure. The 70 feet has quicksand below it, which prevents the flow of

Driller's record of waterworks well No. 8.

	Thickness.	Total.
	Feet.	*Feet.*
.....	4	4
.....	12	16
.....	21	37
low; stronger flow at 44 feet.....	10	47
.....	10	57
.....	9	66
ater.....	2	68
.....	9	77
.....	4	81
.....	9	90
ıy.		

well was a failure at this depth, but a dynamite cartridge ; 43 feet blew the casing off at that depth. The well then ; a tremendous rate for several months and was called the 'ell of the lot."[a]

Driller's record of waterworks well No. 9.

	Thickness.	Total.
	Feet.	*Feet.*
d.....	5	5
.....	7	12
.....	38	50
low.....	2	52

well is 20 feet south of the bank of the river. The gravel at ›m of the well is very clean."[a]

[a] Record in waterworks office.

Driller's record of waterworks well No. 10.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	6	6
Gravel	9	15
Clay	7	22
Sand	12	34
Clay	16	50
Sand	20	70
Gravel with flow	3	73

This well is 65 feet southwest of No. 9 and 50 feet east of No. 2. "There is considerable coarse sand and fine gravel at the bottom of this well. The well was nearly lost by driving through the vein of water-bearing gravel, hoping to shut out the sand."[a]

Driller's record of waterworks well No. 11.

	Thickness.	Total.
	Feet.	*Feet.*
Muck	4	4
Sand	6	10
Gravel	20	30
Clay	10	40
Gravel with flow	5	45
Clay	3	48
Sand	3	51
Clay and sand mixed	5	56
Clay	13	69
Gravel with flow	1.5	70.5

This well is 60 feet south of No. 9 and 50 feet west of No. 6. "Not a strong flow; about the same as No. 5."[a]

Driller's record of waterworks well No. 12.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy clay	3	3
Clay	3	6
Sand	23	29
Clay	44	33
Gravel with flow	17	50

This well is 50 feet west of No. 3 and in line with Nos. 2, 3, and 4.

Driller's record of waterworks well No. 13.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy clay	3	3
Clay	4	7
Sand	3	10
Sand and clay	15	25
Clay	7	32
Gravel with flow	2.5	34.5

This well is 60 feet north of No. 12 and 60 feet west of No. 8. "The effect on this well of dynamiting No. 8 was to almost stop the flow of water in it."[a]

[a] Record in waterworks office.

BURNS TOWNSHIP.

This small area, covering about 1 square mile (fig. 41), is in the ley of one of the minor branches of Shiawassee River, 3 miles st of Byron, and at present has two wells. One of these has a flow, but with a slight head. The other has a pump attached it, but flows through a branch pipe to a watering trough at a el below the pump platform and sometimes flows from the spout the pump. It seems probable that other flows would be obtained putting down wells near the level of the stream, but at present lands adjacent are used only for pastures and fields and the d of wells is not great.

Fig. 41 shows the approximate locations of the wells. Tabulated ta follow:

Wells of Burns Township area.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute. Present.	Flow per minute. Former.	Quality.	Temperature.	Water bed.
		In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*Gals.*		°*F*	
F. Robacher	1901	1.25	25	845	+5	0.75	1.5	Hard; iron	50.2	Sand.
J. A. Holcomb	(?)	1.50	20±	835	+2	1.5	.....	.....	.....	

There is reported to be a flowing well in sec. 3, Burns Township, a creek valley on the farm of J. S. Smith. It is 84 feet deep and nches in diameter, and was made in 1884 at a cost of $30. It ws about a barrel an hour and has ead of about 1 foot. These data from a water-supply schedule tained from Mr. Smith by W. F. oper.

Byron is located on a broad gravelly race, 30 or 40 feet above Shiassee River. The water supply is stly from dug wells or from tubudriven wells 15 to 50 feet or more ep, none of which flow.

A small amount of water is mped from the river for use in ilers and for watering stock.

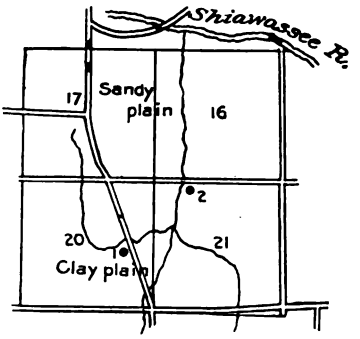


FIG. 41.—Sketch map showing location of flowing wells in Burns Township, Shiawassee County.

On the lowest river terrace, near the dam, there was formerly a ring of considerable size, the water of which was strongly impregted with iron salts, as shown by the pebbles in the vicinity of its tlet. This spring is now closed up by the owner, who filled it th clay.

It is probable that good supplies of water could be had by sinking tubular wells on the lowest terraces of the river, with excellent chances of flows, if the town should ever need a public supply.

VERNON TOWNSHIP.

DURAND.

Durand is located on a very gently undulating plain. The town has a public waterworks, the water being obtained from a group of driven wells near the business center of the town, where the pumping station is situated. The wells are from 40 to 75 feet deep, with one which has brackish water at 150 feet. The shallower wells have fresh water. They were put down in 1901. The supply is not large, and test wells have been put down in other parts of the town to locate additional sources of supply.

There is a flowing well in the western part of the town, which is said to be 287 feet deep and goes a short distance into rock. The water from this well is rather strongly impregnated with mineral matter and slightly brackish to the taste, but is used for drinking and domestic purposes by the people in the vicinity. The flow now is only about 2 gallons a minute, with a head of more than 2 feet. The temperature was 51.8° F. in July, 1904. Near by this well is a second flowing well, of whose depth no record could be obtained, but as the water is of different character and temperature from that of the first, it is probable that it is from the drift above the rock. This water is hard and contains considerable iron, but is not saline. The head exceeds 18 inches, the rate of flow is 1.5 gallons a minute, and the temperature 50.9° F. This lower temperature would indicate a less depth than that of the first.

In the same block, to the east of these two wells, is a third, which formerly flowed at a height of 6 or 7 feet, but which was stopped apparently by the putting down of the deep well. The water at present just reaches the surface of the ground.

It was reported that feeble flows of a temporary nature had been secured a short distance south of town by driving short lengths of pipe into the ground in a swampy area of pasture land. None of these wells, however, are now in operation.

VERNON.

This village is situated on a morainal ridge and is without any public water supply. The wells are all from the drift, the deepest being about 50 feet. The depth to rock surface ranges from 50 feet in the valley of the river to 80 or even 100 feet on the higher ground. The supply of water obtained from the wells here is probably sufficient for present needs and is of good quality.

n the farm of John Pierce, one-half mile south of Vernon, is a from the rock, 100 feet or more deep, the water from which is salty for use.

CORUNNA.

'orunna, the county seat of Shiawassee County, is situated on slope of a faint morainal ridge on the south side of Shiawassee 'er.

'he greater number of the wells of the town are shallow, but give abundant supply of good water.

n 1903 a public system of waterworks was installed, the pump-station being located near the railroad station, on the south side he town. A considerable part of the water now in use comes n driven wells only 30 to 40 feet deep, which give very good. er, but a part of the wells are from 90 to 120 feet deep, pene-ing sandstone from 40 to 60 feet. The water from these deep : wells is said to be soft and free from lime compounds.

n interesting fact is reported regarding these rock wells, namely, pumping one of them affects the others 300 or 400 feet away, sug-ing a coarse texture in the sandstone or communicating fissures g which the pressure is carried.

block east of the court-house, in the lumber yard of H. T. Wilson, shallow bored well 18 feet deep, which in wet seasons flows from spout of the pump, 2 feet above the ground. It was formerly a ing well, but the pump was put on to insure a supply at all seasons. er wells of the same depth in the neighborhood were said to flow nerly, but all ceased some time ago.

he valley between Owosso and Corunna seems favorable for the irrence of flowing wells, as the water in the wells along the margin he valley, even the shallow ones, shows a tendency to rise in the 's in some cases nearly to the surface of the ground.

The depth to rock at Corunna near the railroad station was stated driller at work there to be 72 feet. According to another driller, sident of the town, rock is from 60 to 75 feet below the surface. A in the park is said to be 120 feet deep and about 35 feet into the . This is near the river at the lowest level of the town. Another rmant says the rock surface is only 50 feet down.

WATER SUPPLIES OF SAGINAW COUNTY.

GENERAL STATEMENT.

'his county was not visited in 1904, because it had already been lied by State Geologist Alfred C. Lane and his assistant, W. F. per, a short time before. Their notes were placed at the writer's osal, and from them the present report is principally compiled. the State inquiry was made with somewhat different ends in view,

it was found impracticable to construct tables for the county such as accompany the reports on other areas.

Saginaw County lies south of Saginaw Bay, within the region formerly covered by a Glacial lake at a higher level than the present bay, and is very flat, with practically no relief forms except the shallow valleys of the numerous streams which cross it, and a few low, narrow, and irregular ridges of sand, sometimes blown up into dunes. The surface rises gently from the level of Saginaw Bay to about 100 feet above it along the southern, eastern, and western borders. The soils are principally heavy clays and clay loams, generally rather impervious to water, with scattered, more or less irregular, tracts of considerable extent composed of sands and sandy loams, deposited chiefly by the Glacial lake. These are easily penetrated by water, and differ greatly in this respect from the clay types of soils.

The depth to bed rock is somewhat variable in spite of the flat surface of the county, and is remarkably irregular in some localities, with variations of about 200 feet in short distances, showing that the rock surface here had hills and valleys before the present deposit of drift was left upon it. So far as is known the rock is nearest the surface a mile or two south of St. Charles, where it is from 35 to 45 feet below, and ranges from this to 200 feet below about Merrill, 250 feet below just west of Saginaw, and more than 260 feet below in the northern part of Swan Creek Township. The variations in depth are sometimes so abrupt that a well-marked valley can be traced for some distance, where drill holes are frequent, and such valleys afford an excellent supply of water, because they are generally filled with relatively coarse material. In such cases it is probable that no inconsiderable part of the water comes from the rock walls of the valley, where the eroded strata come into contact with the material which fills the valley.

The county is watered by four large but sluggish rivers and by numerous smaller streams which come in from various directions. The rivers finally unite near the city of Saginaw, forming Saginaw River. These numerous waterways, and the low gradient of most of them, produce extensive overflows during the wetter parts of the year, causing a large part of the low land to be swampy before the settlement and draining of the region.

Because of the type of soil and because the overflows continued more or less frequently after the land had been cleared and drained, the water obtained from open, dug, shallow wells throughout the greater part of the county, was never entirely satisfactory or wholesome for drinking and other domestic purposes. The compactness of the soils, especially after drainage had been artificially improved, made the supply from this type of wells small and uncertain in quantity.

As a result of these conditions, early attempts were made to secure tter and more certain supplies, and bored, driven, and drilled wells considerable depth, drawing on the water from lower water-bearing rata, became common. In many cases these deeper wells extended wn into bed rock, and here, while abundant water was found, in any cases it was brackish or salty, sometimes so much so that it was possible to use it for many purposes.

In the sandy districts and the higher parts of the county the upper ound waters are often more abundant and wholesome, and here dug ells may give a sufficient supply, although even in these districts the ep tubular wells are frequent and are the most reliable.

The impurity of the water from shallow wells was due in part to the eat accumulations of organic matter in the soils and in part to the adiness with which unwholesome and disease-impregnated matter und its way from the surface into the shallow basin wells, both by ashing in at flood time and through fissures in the soil formed during rought. Aside from this, water from the clay is usually very hard nd liable to be roily from the ease with which the finer matter of the ay is washed into the wells and the length of time which it remains uspended after it once mixes with the water. The water of such dug ells is sometimes colored brownish or blackish by organic matter.

The water from the deeper layers of the drift, or clays, is usually ard, with considerable iron in it, but not enough to make any change i its appearance. The amount of hardness is variable, and without pparent reason, except that the beds from which it comes are variable i the amount of soluble calcium salts they contain.

It is frequently true that the best and most certain supply of water om the drift is found just above the rock surface and in districts here the drift is very compact and fine grained, as in and around aginaw; this supply is the one most depended upon for ordinary arm and domestic uses. This water is fresh, or only slightly saline, nd often very hard. In and near Saginaw this supply is somewhat ffected by leakage from abandoned salt wells, and is more or less rackish in consequence.

The rock waters, though often brackish, and occasionally so salty hat they are not used for drinking or cooking, are in some cases, here sandstones are the source, much freer from hardness than those rom any other source.

At from 200 to 300 feet down the salt content increases and becomes too high for any ordinary use; even stock will not drink it. At a depth of 300 to 500 feet a strong impure brine is struck, and below this, at from 650 to about 1,000 feet, the brines are found from which the Saginaw Valley salt wells have drawn supplies, which have yielded enormous quantities of salt, and which are still capable of great development.

WASTE WATER.

In a region so flat as this, where the soil is not absorbent, the disposal of the waste water from flowing wells is often a rather difficult matter. The usual method is to turn it into the roadside ditches and give it no further attention. Here it forms stagnant pools, in which mosquitoes and gnats breed in abundance, and in which various water-loving plants flourish and help by their growth to clog the ditches, thus impairing their efficiency and shortening their period of usefulness to a very considerable extent. A much better method of procedure would be to turn the water over some considerable area of cultivated land by means of irrigating ditches, or better still, probably, to carry the pipe or casing up nearly to the level of the head into a large tank, and allow the water to rise in this to the level of the head, but not overflow, as at the level of the head the water would stop flowing until it was needed and drawn off, when it would begin to flow again. A properly fitted valve or cock could be placed in the casing to draw off water for domestic use, while the water could be distributed automatically to various points where it is needed, as it often is where a windmill pump is used to fill a tank. Such a method would not only make it unnecessary to dispose of waste water, but would tend to conserve the supply. The cost of this type of trough or tank would not usually, where the head is slight, be great, and in most cases would be less than the cost of putting in a drain to carry off the waste.

CATCHMENT AREA.

The shallowness of some of the wells (from 10 to 25 feet) is an indication that the water-bearing strata are not, for these depths at least, extensive, nor can they be continuous for any great distance. Hence it is not likely that they reach to the nearest high land, which is several miles away to the west. These facts would lead to the conclusion that the catchment area is in the immediate vicinity, and it may lie in a district of heavy sand to the west and northwest, 2 or 3 miles from the shallowest wells, especially as the land rises slightly in these directions. The sands would readily absorb a large amount of the rainfall; and if the underlying strata are sufficiently permeable to take in this supply, or a large part of it, it is probable that this is the catchment area.

FLOWING WELLS.

FLOWS FROM ROCK.

Flowing wells are numerous, and from a number of horizons, both in the rock and in the drift. Of the rock it may be said that, if the well is drilled deep enough, flowing water would be obtained in almost any part of Saginaw County; but it must be remembered also that the water would generally be salty if the well penetrated the rock for any

siderable distance. Hence it is not wise to go too deep for water farm use when trying for a flow.

. well on the north side of sec. 2, Chesaning Township, 350 feet p, with rock at 60 feet, flows salty water. Another in the same ghborhood is 180 feet deep with fresh water, and is 130 feet in the k. Still another is 150 feet deep, and flows slightly salty water. the east side of sec. 1 is a flow 120 feet deep, with rock at 47 feet. the south side of sec. 5 is a flow 117 feet deep, with rock at 45 feet, d on sec. 17 is a flow 250 feet deep, with rock at 65 feet. The temrature is reported as 54° F.

The pump wells range, for drilled wells, from 61 feet deep with 10 the rock, to 465 feet deep with 405 in the rock. In this last the ater was fresh down to 260 feet, below which it was salty. The ck surface is reported as 119 feet deep on the north side of sec. 23, feet deep on the south side of sec. 5 and the north side of sec. 2, 47 et on the east side of sec. 1, and 70 feet on the south side of sec. 2.

FLOWS FROM DRIFT.

The flows from the drift are confined to definite areas. If a line is awn from north to south through the middle of the county, all but e group of flows from the drift will be found on the western side of The exception is the area in Birch Run Township, in the extreme utheast corner of the county. All of these areas are on plains, with noticeably higher land near by, yet the gradual rise toward the rder of the county is sufficient to furnish head.

There are seven areas in which three or more flows occur and five lated wells apparently remote enough from other developments to considered independent areas, thus making 12 in all. These areas e located as follows: (1) The Merrill area, in T. 12 N., R. 1 E., extendg from Merrill north and northeast; (2) a single well in sec. 1, Lakeld Township (T. 11 N., R. 1 E.); (3) an area of considerable extent in arion Township (T. 10 N., R. 1 E.); (4) the Brant area, in the northst part of T. 10 N., R. 2 E.; (5) a single well in the south part of the ne township (sec. 33); (6) the Fremont area, in the eastern part of 11 N., R. 2 E., and along the line between this and the next township t; (7) the Swan Creek area, in the northeast corner of T. 11 N., 3 E., near Swan Creek post-office; (8) an isolated well on sec. 18 10 N., R. 4 E.); (9) three wells near Luce post-office, in Albee Townp (T. 10 N., R. 4 E.); (10) the Birch Run area in the southeastern t of T. 10 N., R. 6 E.; (11) a single well in sec. 1, Chesaning Township 9 N., R. 3 E.); (12) a single well at Frost post-office.

As the slope of the country is toward the north and east, it is probe that the valleys of streams and other depressions in that direction y yield flows beyond the limits of the present development.

FLOWS BY DISTRICTS.

MERRILL AREA.

This is known to cover about 10 square miles, and is the most extensively developed area of flowing wells from the drift in Saginaw County. Merrill lies on the southern border of the area, from which it extends north and northeast; in it the majority of the flowing wells of the district are found, about 25 being reported from there, the water coming from depths varying from 35 to 150 feet from sand or gravel strata.

It is possible that conditions here are similar to those of Alma (see p. 207), with coarser layers interspersed with the finer. The fact that wells near together are of very different depths points to this as a possibility, but in the absence of accurate records of the wells nothing definite can be stated.

North of Merrill the depth is generally 60 to 70 feet, but some wells are only 10 feet deep. None that flowed is more than 100 feet deep, so far as learned.

The water in the flowing wells, as in the other wells of the Merrill area, is hard and more or less impregnated with iron and carbon dioxide. It is otherwise of excellent quality and is wholesome and good.

In general, the head of wells of this area is slight, being only 1 to 3 feet above the surface. But the well of Mr. Dubay, 1 mile east and three-fourths of a mile north of Merrill, is reported to have had a head of 11 feet. This well is also reported to have the largest flow in the area—10 to 15 gallons a minute—from a depth of 65 feet. The average flow of wells in this area is, however, small, 1 to 5 gallons a minute, except in a few cases where the flow is from a dug basin, in which case the amount of water running away seems to be larger.

MARION TOWNSHIP.

The Marion area is about 6 square miles in extent, is narrow, and trends from northwest to southeast. It includes about 20 wells, ranging from 60 to 102 feet in depth. The records available indicate that after a shallow bed of sand and gravel 2 or 3 feet deep has been passed there is a thick bed of clay, with occasional thin beds of gravel from which the water comes. The flows are usually small with slight head, but sufficient for farm and domestic uses.

BRANT AREA.

The Brant area is about 7 square miles in extent and as developed has 11 flows, all but one being from the drift. These wells range from about 75 to 140 feet in depth, several of them being between 90 and

feet, and only two more than 100 feet deep. At Brant post-office flowing well from the rock, 282 feet deep. It is probable that in area a larger number of flowing wells may be developed. The low ınd along the streams and the sags in the general surface would be most favorable places to test.

'he single well in the southwest corner of sec. 33 of Brant Township 0 feet deep, and from its location would seem to be independent of area to the north of it. It is possible that explorations along the 'k valley in this vicinity would yield other flows.

FREMONT TOWNSHIP.

'he Fremont area covers 4 or 5 square miles and, as developed in 0, included about a dozen wells which flow from the drift. In this a the majority of the flowing wells were reported to be 42 to 85 feet p, but one, in the southeast corner of sec. 12, is said to be 212 feet p, entirely in drift. This is the more probable, since about 1 mile th and one-half mile east is a pump well 260 feet deep, in which the k was not reached; on the other hand, there is a well on sec. 14, y 2 miles southwest, in which rock is reported at 145 feet. In se wells the general report is that they are in clay from the surface wn, the water coming from gravel or sand strata. The flows are orted as medium or small.

SWAN CREEK AREA.

The Swan Creek area is located 3 miles east and 1 mile north of the emont area and is much smaller, consisting of three wells along the rth and south road between secs. 3 and 4. The wells are all of difent depths, that of the southernmost being 58 feet, that of the thernmost 78 feet, and that of the one between 69 feet. These lls are all reported as being through clay to the water-bearing atum, which is sand or gravel.

This area may possibly be extended both north and south along the ley of Swan Creek, which lies one-half mile to the east of the pres- development, but at present this district is not settled thickly.

LUCE AREA.

Near Luce post-office, in Albee Township, is a group of three small ıs, 32 feet deep, which are reported to pass through 3 feet of sand, n shallow sand and gravel, and then clay to the water-bearing vel. Further testing may increase the extent of this area, parularly to the west

ALBEE AREA.

The single well on sec. 17, Albee Township, is 49 feet deep, with a small flow, in a relatively unsettled region. Further prospecting may extend this area to the north.

BIRCH RUN AREA.

This area is about 5 square miles in extent and is situated on the inner slope of a low morainal ridge, which just touches the southeast corner of the township and county. The slope of this ridge is gentle, but the differences in elevation here reach the maximum for this county, and amount to 30 or 40 feet to the mile. The flowing-well district lies near the foot of this slope and has its greatest length parallel to the axis of the ridge.

The development of this area is small, only 8 wells being reported in it, and these range in depth from 25 to 65 feet. The water in some of the wells is reported to come from sand sufficiently fine to work into the casing and obstruct the flow. The rock surface within the limits of the area is from 60 to 90 feet below the soil surface and flows from the rock are not infrequent in the vicinity of the area. The drift flows give hard water in sufficient quantity for ordinary farm uses, though the wells tend to clog rather quickly, as mentioned above.

The catchment area is probably the morainal ridge, from which is also derived the pressure which develops the head of the wells. The area might be extended to the northeast and to the southwest of its present development if care were taken to locate the wells in depressions below the general surface.

CHESANING AREA.

The single well from the drift in Chesaning Township, of which any record was obtained, is that of C. M. Johnson, which is only 18 feet deep, from a small vein of gravel in the clay. The water is hard and fresh. This is probably due to a purely local development of conditions favoring a flow.

THOMASTOWN TOWNSHIP.

As developed at present, this area has but a single flowing well from the drift, that of William Wurtzel, at Frost, 10 miles west of the city of Saginaw. This well is situated in the valley of a small stream, being developed in 1896 while boring for silver. The flow was struck at 40 feet, the water spouting out of the casing several feet above the ground. The flow is still good and the temperature is about 45° F.

This water is sold under the name of the "Wurtzel Saginaw Magtic Mineral Spring Water," and its character is shown by the follow-g analysis:

Analysis of Wurtzel Saginaw Magnetic Mineral Spring Water. [a]

	Parts per million.
lorine (Cl)	1,460.90
dium (Na)	949.82
lcium (Ca)	260.62
lphate radicle (So_4)	201.89
agnesium (Mg)	54.76
on (Fe)	1.48
lica (Si_2O_4)	16.44
rbonate radicle (CO_3)	255.25
	3,201.16
ganic matter:	
Free ammonia	15
Albuminoid ammonia	05
	20

Dr. R. C. Kedzie, analyst.

It is not known that any other flows have been struck in this vicin-y, but it seems probable that by making careful explorations others ight be developed near the stream level.

SAGINAW WATER SUPPLY.[b]

The city of Saginaw has two pumping stations, inherited from the ne when there were two corporations. Both of them draw water om the river, the West Saginaw plant from the center of town, ar Court street, the East Saginaw plant from farther up the river, ing located at the corner of Lane and Douglas streets, about one-urth mile below the junction of Tittabawassee and Shiawassee rivers. either of the supplies is considered wholesome. They are used pri-arily for fire protection and incidentally for lawn sprinkling, etc. or drinking purposes the city has put down a large number of drilled ells. The last detailed list of these at hand gives 20 on the east side nd 10 on the west side, the depths ranging from 120 to 185 feet. Iany have been made since, and probably there are now (1905) twice s many. All draw their supply from sandstones of the coal meas-res. Bed rock is usually encountered at 80 to 100 feet, and not nfrequently water is found in pervious beds at the base of the drift, out never in such quantity and quality as to be satisfactory for a water supply for so large a population (52,428).

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] By A. C. Lane.

Besides these city wells most of the hotels and many of the factories and private institutions have similar wells. Analyses of well water and of Saginaw River water are given in Water-Supply Paper No. 31.

Saginaw River is practically a dead-water estuary as far up as Saginaw, and the current runs up or down, according to the wind, the rainfall, and the fluctuations of the Great Lakes. A table of elevations showing the height of the river each day and month from 1887 to 1890 is given in the first annual report of the board of public works in 1891, which shows plainly a correspondence between these fluctuations and those of Saginaw Bay. The range is from 6 feet above to 3 feet below the datum. There is no especial safety to be gained by going upstream, and there is no available safe supply within easy reach. A thoroughly effective system of filtration seems to be the proper means of obtaining a safe city supply.

Some years ago a well was dug and bricked down about 80 feet, but then encountered such a rush of water and quicksand as to endanger the life of the man in the well and to fill the well with quicksand. More recently, in the spring of 1903, a well was put down in the "middle ground," a former island in Saginaw River, to test the water supply. It passed through lumber waste and sawdust, and at 12 feet struck river sand, then clay; at 42 feet it reached fine gravel, and from 44 to 53 feet coarse gravel. While there was quite a volume of water, it was contaminated from the old salt wells, and ran up to 2,809 parts per million of solids and 87 per cent hardness.[a]

WATER SUPPLIES OF GRATIOT COUNTY.

GENERAL STATEMENT.

Gratiot County is just west of Saginaw County, and is partly within the morainal region and in part within the area formerly covered by a Glacial lake. The western half, approximately, is rolling, the ridges running in a general north and south direction, while the eastern half is a plain sloping to the east and south. The western and northern parts of the rolling area are higher and usually more sandy or gravelly than the eastern, and have been cleared and settled but a short time.

The principal stream of the county is Pine River, which flows along the western border and northwest corner. The southern half drains into Maple River, and thence to Lake Michigan, while the northeastern third is drained by small tributaries of Shiawassee River, which leads to Saginaw River and the bay. The streams are small, and in the smaller ones there is little or no water during a large part of the year. These natural waterways have been extensively added to, in the flat portions of the county, by large ditching

[a] Helm Brothers, analysts.

rations, so that portions of the area are overdrained except for a rt flood time in the spring.

The rolling portion of this county, as in the others discussed, has e more penetrable soils, with strata capable of storing large ounts of water near the surface. Hence in this area the wells are t usually deep, many of them being of the open dug type, with ne sewer tile or cement curbing. Such wells are often as shallow 10 or 12 feet, while they sometimes reach a depth as great as 60 t. They frequently yield abundant supplies of excellent water; t where they are in the depressions and valleys the supply is larger d less affected by drought than it is when they are on the slopes tops of the ridges.

Tubular wells are general in almost every neighborhood in the rolling portion of the county. In a list of over 200, furnished by Mr. hivers, of Alma, the greatest depth reported was 195 feet, reached attempting to increase the flow of a shallow well, while the shallowest was 13 feet deep. About one-half the entire number were ss than 55 feet deep, while less than one-eighth were over 100 feet. Of the entire number nearly 25 per cent were flowing wells, located hiefly in the Alma area.

In a list of wells on the farms of Mr. A. W. Wright, of Alma, in the townships of Arcada and Pine River, in the same region, 17 wells are reported. Of these all but four are more than 100 feet deep and two are over 200 feet, the deepest being 218 feet and the shallowest 45 feet. These are nearly all pump wells, equipped with windmills.

There are several areas of flowing wells in this part of the county, the most extensively developed being in Alma.

On the lake plain the supply varies with the character of the surface deposits, whether they are sandy or loamy, as they are in certain parts of the district, notably along its border, and in the vicinity of Ashley, Breckenridge, and Wheeler, or whether they are compact clays, as they are over the greater part of the district. Where the surface is covered with sand or gravel strata, overlying clay, the wells are shallow dug basins from 8 to 20 feet deep, and where the clay type of soil is general, the wells are tubular and may be very deep, in a few cases running down over 300 feet and then getting only small supplies of water. The deepest drift wells in the county are found in Lafayette township, where a few wells nearly 400 feet deep have been drilled. In this part of the lake plain tubular wells are more common than in the rolling country, and probably average deeper. In the western part of the lake plain shallow dug wells are the main water supply.

The only rock wells in the northwestern part of the county are the salt wells at Alma and St. Louis, where the rock surface is down 325 to 500 feet.

In the southeast corner of the county, around Ashley and Bannister, the rock surface is not so deep as farther north, and here are many rock wells, a considerable number of which flow. In the same part of the county are areas of flows from the drift, while dug, bored, and drilled wells of various depths reach small supplies of water in the more porous strata of the drift, but the largest and most permanent supplies in this district come from the rock, which ranges from about 20 feet in sec. 24, Elba Township, to about 150 feet in the vicinity of Ashley.

The western part of the district depends mainly on shallow bored or dug wells for its water supply.

SUPPLIES BY DISTRICTS.

ARCADA TOWNSHIP.

ALMA.

Alma is situated in the northern part of Gratiot County, on the broad terraces and slopes of the shallow valley, here a mile or more wide, in which Pine River flows.

Public and private supplies.—The public water supply is furnished by a well-equipped municipal plant in charge of a public board, which has leased the pumping for a term of years to a private company which controls the water power developed by a dam in the river. The water is pumped from Pine River, below the dam, the direct system of distribution being used, and serves to give fire protection and street, lawn, and garden sprinkling, and also water for flushing, sanitary purposes, and manufacturing. There is a well-planned and partly developed sewer system.

Since the public supply is not safe to use for cooking, drinking, and other potable purposes, a supply is obtained for these us s from dug and driven wells of various depths—from less than 10 to 150 feet. Shallow dug wells are the only source of water for domestic use in some parts of town, and in a number of cases the water used by a family was reported to come from a basin made by sinking a single sewer tile of large diameter in the cellar of the house, the water rising in this sufficiently to be dipped or pumped out. This type of well is found at the foot of a low ridge with sandy slopes which runs irregularly across from the western to the northeastern part of the city.

A second kind of well, common in the higher parts of town, is made by sinking a cement cylinder through the clay to some water-bearing stratum 15 to 30 feet down; this and the sewer-tiled well are about equally popular. Deeper wells are generally drilled or driven, and are 50 to 100 feet deep.

Flowing wells.—In the parts of the city on the terraces of the river valley, however, the greater part of the water used for domestic pur-

omes from flowing wells, a great development of this supply been made here (fig. 42).

area of the present development is small considering the large r of wells, for the total length of it is somewhat less than 1½ miles

the lower terraces of the river and the greatest width about a r of a mile.

wells are all or nearly all driven or drilled, and are from 20 feet to 150 feet in depth, and vary in the rate of flow from less than a 20 or more gallons a minute. The head where greatest is only 18 feet *above the level of the* mean water level of the river.

The water is invariably hard, and contains a considerable amount of iron in the form of the acid carbonate; enough to give a distinct blackish coloration to strong tea if turned into it when fresh from the well. The water also deposits these salts in the form of abundant reddish or yellowish incrustation on the surface of the glass and crockery ware in which it is allowed to stand. This incrustation is so closely adherent that it can be removed only by the use of some acid. The water also actively attacks tinware and soon rusts holes in it.

The water when fresh from the wells contains an excess of carbonic acid, which decomposes on exposure to the air, the carbon dioxide passing off and the calcium and iron bicarbonates (which are also decomposed) being in part precipitated as the normal carbonates, forming the incrustations mentioned above and the tea-kettle scale. The carbonic acid is probably the active agent in rusting the tin.

The water, although somewhat heavily charged with mineral matter, is a good chalybeate (iron) water, and except in certain cases should be as healthful as any ground water in this region. A certain amount of the excess of lime and iron may be removed by boiling if in any case this is considered desirable.

The water is reported to come from a thick bed of sand, with gravel intermixed, apparently in beds of small lateral extent and rather slight thickness. The only well which has been put down to the bedrock is the deep mineral well at the Alma Sanitarium. The driller's record of this is as follows:

Driller's record of Alma Sanitarium well.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	60	60
Quicksand and water sand	97	157
Gravel	3	160
Clay and gravel	315	475
Sand and gravel to bedrock	25	500

This record is in part confirmed by the report of Mr. Harry Chivers, of Alma, who kindly furnished the following record of the east town well, put down by him in 1904. Aside from those of the sanitarium this is the deepest well in the city.

Record of east town well, Alma.

	Thickness.	Total.
	Feet.	*Feet.*
Hardpan (clay till, rather compact)	50	50
Sand	93	143

Mr. Chivers also reports that in general throughout the city the hardpan or clay on the higher elevations is about 70 feet thick, vary-

from this to about 40 feet near the bottom of the valley. Below s depth it is rather rare to find clay, but beds of coarser sand and vel in the finer sand bed are not uncommon, and from these the wing water comes.

It is apparent that this stratum of the drift consists of a very thick d of permeable material, which has scattered through it coarser ds of greater or less extent, through which water can move more pidly if opportunity offers. The fine sand is very greatly in excess the coarser gravel, both in thickness and in area, and, while it conins water, probably to the point of saturation, will give it up to the re permeable gravel rather slowly. However, because of its eater abundance, the sand will yield a total amount of water ich will always keep the gravel full unless the drafts on the latter e very heavy.

Although the sand itself, because of its relatively small capacity of ansmitting water, will not yield flows or even supply pumps of dinary capacity (unless large-sized pipe is used, a thing not comonly done), it nevertheless serves an important purpose, for, being ore or less completely saturated, it serves as a capping stratum to e gravel, and, as back from the valley it rises to a greater altitude an the wells, it may be a chief agent in causing the flows from the arser material.

It is probable that the whole or some part of the margin of this eposit of sand is more or less exposed, either directly at the surface r through permeable beds of surface material, to the rain water as it oaks into the ground. This exposure needs only to be far enough bove the level of the height to which the water rises in the wells to hold the ground-water level sufficiently high (allowing for a certain loss due to friction) to give the existing pressure or head, which is about 18 feet above the river. This would not require land any higher than much of that which lies west and north of the city, and it is in this region, in all probability, that the catchment area lies, as the surface rises steadily in these directions. But it is also likely that all of the surrounding country to some extent contributes to the supply from its ground water. The head here could not have its origin in the region to the east and northeast, for this is too low, and the same may be said of the region to the south, where also the soil may not be sufficiently porous to take in the requisite amount of water.

As the development of the area at the lower levels, near the bottom of the valley, has gone on there has been a gradual lowering of the head of the wells of the higher parts of the town, and not a few wells which formerly had good flows have ceased entirely, and are now pumped or flow below the level of the surface.

A very large part of this permanent lowering of the head is due to entirely useless waste, which may even be a detriment to the

owner in that it compels him to maintain a larger drain to carry off the water than would otherwise be necessary. Sometimes the waste is larger than necessary, because of thoughtlessness or indifference, but in most cases it seems to be due to the owner's vanity. He likes to have it said that his well has the largest flow in the neighborhood, and he does not consider that this spirit may eventually, or even immediately, cut off the supply to some other owner entirely and put him to the expense of providing a pump. By inspecting the list of wells it will be seen that some are allowed to flow at the rate of 10 gallons or more a minute, or more than 450 barrels per day—an amount enormously beyond the needs of any family or any neighborhood. Two wells at the lowest level of the river valley, very near the level of the water, were, at the time of the writer's visit, flowing the full size of the casing at the level of the ground and the water was not being used at all, as the wells were located on vacant land. These wells, because of the low level at which they are placed, have undoubtedly been a chief cause in lowering the general head of the area, as they have been running a number of years, except for brief intervals, when they have been temporarily closed.

Alma is justly proud of these flowing wells, and it would be wise for her citizens to guard against the waste of this important natural resource by reducing the size of the flows of the wells near the river and in other low places to something like the needs of the owners. If the structure of the water-bearing beds is as explained above, then the waste of any large amounts of water from any well will affect the whole supply and tend to decrease the flows of all the wells, and of course this tendency will be first noticed in the wells nearest the level of the head and later on the lower ground. The wise thing to do would be to reduce the size of the outlet pipes in all the wells to such a diameter as will give water enough for the needs of the owners, but not allow any large waste. It would be very rare, indeed, that any family could not get all the water it needed from the flow which would run through a pipe one-fourth of an inch in diameter, and except in special cases this should be the size used.

Aside from waste there are a number of other causes which in individual cases are responsible for diminution or cessation of the flow. Among these are leaking through or around the casing, the filling of the lower part of the well tube with fine sand, the clogging of the strainer by fine silt or mud or by incrustations, as discussed on pages 128–130, and probably also the general lowering of the ground-water level in the catchment area during dry times, which affects all the wells to a greater or less extent, those on higher ground first and most

From consideration of the height to which the water will rise above the level of the river, it is evident that all parts of the river valle

hich are more than 17 feet above this level will be too high for flows, » any extension of the area will be confined to the lower parts of the alley.

Since the lower terraces of the valley are generally narrow, and in laces, both above and below Alma, disappear almost entirely, it is vident that the area of flowing wells can not be greatly extended. nfortunately, no records are available which give any correct idea of ne directions in which the water-bearing sand extends, for, as will be een by inspecting the tables of the Alma wells (pp. 210–211), the depth » water is variable in the area, some well getting its water from nearly very foot of the vertical distance within which the beds have been xplored, a fact which makes it practically impossible to identify the rata in isolated pump wells beyond the area of flows. It is probable, owever, that both up and down the river valley for some distance ows could be obtained on the lower terraces of the valley, and it is uite possible that the Alma, the St. Louis, and the Jasper Township reas may all eventually be connected along this valley by continuous nes of flowing wells.

The great depth to bed rock in this vicinity (nearly or quite 500 feet, s shown by the record of the Sanitarium well, p. 211) and the fact that he overlying drift contains abundant supplies of good water, have made t a rare thing for wells to reach down to the rock. At the sanitarium, owever, is a rock well 2,860 feet deep. At this depth the water is ery highly charged with salt and other mineral matters and is used nly for medicinal purposes and baths and in the manufacture of sevral proprietary articles. The water in this well rises nearly to the urface.

The fact that at Alma the rock surface is 500 feet below the surface of the ground, while at St. Louis and Ithaca the depth is about 150 feet less, the ground surface being about the same level, indicates the presence in the rock surface of a valley which has been buried by clay and gravel deposits. Such buried valleys are often important factors in producing flowing-well areas, although here the bottom of the water-bearing stratum is so far above the level of the bluffs of the buried valley that this may not have any effect on the head in this area.

The data given in the following table are largely furnished by drillers or well owners. The drillers, except Mr. Hover, of St. Louis, all reside in Alma.

Wells at Alma.

No. on fig. 42.	Owner.	Driller.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Remarks.
				In.	*Ft.*	*Ft.*	*Gals.*	*° F.*	
1	W. A. Thomas	H. Chivers		2	56	+2.5	2.5		Piped underground to outlet.
2	W. S. Turck	do	1895	2	68	+2	1.5	50	
3	do	do	1895	3	60	+1.5	1.5	50	Pasture well.
4	M. Ferris	do	1897	2	32?	+1.25	1.5	50	
5	J. M. Montigel	do		2	72	+1.16	.16	53	First lowered by wells of N. Church (No. 22), then by those of Union School (No. 36), from 3 feet to 0, and from 5 gallons to ¾ gallon.
6	J. Russell	do		2	77	+2	1.25	49.8	
7	A. W. Wright	do	1884	3	125	+0	.75	50	
8	F. C. Keenan	do		2	65	+1.8	1	50.6	
9	Railroad restaurant	do	1897	2	48	+2	2	49.8	
10	M. Pollasky	do	1900	2	57	+3	2.5	49.8	
11	I. N. Brainard	do	1896	2	48	+10	10	49.8	Flow at 25 feet.
12	M. Pollasky	do	1882	2	60	+6	4	50	One of the oldest in town; reduced by No. 13.
13	Mr. Griffeth	do		2	55	+8	6	49.8	
14	D. Adams		1882	2	55				
15	J. J. Glass		1880	2	75	+1.25	.5	51	Head and flow less than at first.
16	A. J. Hall	C. Hover	1893	2	103	+1	.5	50.5	
17	Hotel Fern			2	70	+ .5	.25	50	
18	J. F. Suydam		1900	2	100	+ .5	.25		
19	J. F. Schwartz			2	60	+6			In cellar; used to flow above.
20	G. S. Ward		1903	2	55	+4			Do.
21	W. S. Turck			2	60 (100)	+4			In cellar; flow here formerly at 100 feet.
22	Church Block	Chivers		3	98	+1.	1.25	50.2	
23	E. J. Emmer			2	73				Flow in cellar; pumped.
24	J. Caple			1	65	+1	.25	51	Improved by sand pumping.
25	Alma village (east)	Chivers	1904	3	143	+1.25	2.5	50	Town well, used as drinking fountain.
26	E. Brewbaker			2	60	+2.25	2	49.8	
27	E. Emsley			2	60	+2.5	1	51	
28	J. M. Montigel		1878	3	55	+1.5	1	51	
29	A. D. Woodward			3½	32	+ .5	.12	55	Head 2.5 feet lower than formerly.
30	do			2	50	+1.25	.25	52	
31	M. J. Dallas			2	55	+2.5	2	51	
32	S. Wetherel			2		+2	.25	52	
33	Chas. Deplanty			2		+2	.5	52	
34	H. Brewbaker	Chivers	1897	2	116	+2.5	1	52	Feed barn on Superior street.
35	Electric Light Co		1904	2	50	+16	.5		At power station, bank of river, 8 feet above water; 3 veins of water above this; clay with hardpan between.
36	Union school		1885	2	80	+1.5	1		
37	W. A. Bahlke	Chivers	1888	2	55	−6	1		Flows in cellar.
38	J. M. Montigel			4	65	+6	5	50	Used to cool engine cylinder.
39	G. W. Pringle			2		+2	1	50	
40	H. B. Currence		1903	2	65	+4.5	4	50	
41	George Young		1903	2	70	+3	2.5	50	Opposite residence.
42	T. M. Barker		1901	2	72	+2	3	50	
43	Doctor Pringle		1878	4	85	+3	10	50	Head much more, but cut off here.
44	Mr. Struble			2	71	+4	5	50	Flows at 20 and 40 feet also.
45	E. Amsberry			2	70	+4.5	8	50	
46	H. F. Thompson			1		+3	1	50	
47	W. S. Turck			2	70	+2.5	.25	50	At dairy barn.
48	George Young			2	78	+ .5	1	50	Cut off at −3 feet to secure good flow.
49	C. A. Hicks			2	70	+1.5	2	50	
50	O. M. Gargett		1880	1¼	90	+1.5	.25	50	
51	G. Bildson			2		+2	1.5	50.2	
52	N. F. McCullough			1	60	+ .5	.12	52	
53	Smith & Glass Co.			2	103	+ .5	1	49	Formerly flowed above surface; now cut off in cellar.

Wells at Alma—Continued.

Owner.	Driller.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Remarks.
			In.	*Ft.*	*Ft.*	*Gals.*	*° F.*	
Arcada	Chivers		2	87	+1.5	0.5	50	
bs			1½	60	+2			Nearly stopped flowing; formerly good flow.
rk			2		+2	.25		
adleigh		1885	2		+1	.16	50	
aldwell	Chivers	1898	2	73	+ .75	1	50	
lubb			2	60	+1	1.5	50.5	
arthy			2	55	+6	5	50	
eonard	Chivers		2	55	+3	1	50	
Sanitarium Co.	do		2	56	−2.5	1	50	Park well, flows in bottom of well house; used for medicinal purposes.
ller			2	55	+1	.5	51	
hting			2	60	+1	.5	50	
dson	Chivers		2	58	+2	1	50	
Timby			2	60	+1.5	.5	50	
Smith			2	100	+1.5	1	50	
ring			2	60	+1	.5	50	
Paddock			2	65	+ .5	.25		Now pumped.
nah			2	70	+1.5	.5	50	
illage (west)	Chivers	1904	3	93	+1.25	2.5	50	Used for drinking fountain.
olite			1	55	+3	.12	52	
reamery			3	58	+4	3	50	
t & Moore		1888	3	40	+8	15	50.5	In 1904 flowing full size of pipe, but with diminished head; water entirely wasted.
		1888	3	58	+8	10	50.5	
ardus			2	56	+0	2.2	50.2	Flows at surface, but pumped.
cox			2	55	+ .5	.75	50	
Sugar Co.?			2	55	+ .5	.5		
e Company		1903	2	63				Two wells flow in basement.
Manufacturing		1903	2	53				Flow in basement.
factory								
Chase								
Bennett								No data.
factory								
gkinson	Eagon		2	70	+1	1	50	
gkinson	Chivers		2	67	+1	1	49.8	
et	do		2	83	+1.5	.5	50	
Nelson	do		2	80	+1.5	1	50	
onkite			2	65	+2.5	4	50	
lass			2	22	+1	.5		
ing			2	20	+ .5	.25		
ane								
Smith			2	77	+ .5			Pumped, but would flow a little.
Lane			2	62	+ .5	.25		Now pumped.
man			2	40	+ .5	2		
& Vermenken								
outenberg		1890		12	+ .5	.50		Do.
ely				20				Flow small; pumped.
ihnell				62	−1.5			Pumped.
ig		1893	2	107				Flow in cellar.
ersoll	Chivers	1888	2	93	+ .5	.25		Still flowing, but pumped.
ney			2	93	+1	.33	50.5	Used to flow more; sand has clogged strainer.
ress ?			2		+2	2.5	50.3	
Edwards	Chivers		2	93	+1	2	50	
rk			1	55	+1.5	.5	49.5	
ams	A. Eagon	1886	2	60	+1	.25		
Hollenbeck	do		2	45	+1.5	.5	50	
Valkenberg	Chivers		2	78	+1	1		
rris	A. Eagon		2	90	+0	.5+		Flows top of ground.
erton			2	65	+1.5	1	50	

levation of the wells in the above table ranges from 728 to 746 ve tide. The waters of almost all are reported as hard, with n. The water bed in all is gravel.

Number of wells of different depths.

Depth in feet.	Number of wells.	Depth in feet.	Number of wells.
10 to 20	2	60 to 70	6
30 to 40	6	70 to 80	6
40 to 50	21	80 to 130	4
50 to 60	11		

VICINITY OF ALMA.

Aside from the large development of flowing wells at Alma, which is located in Arcada Township, there is a single small group of flowing wells 2½ miles southwest of the town, on the farm of John Wolf, in the northeast part of sec. 8. This group consists of two wells situated on the terrace of Pine River, a short distance west of the stream and about 15 feet above its level. The flows are small, rising about 6 feet above the surface from gravel 41 feet below it. The water is not so hard as that in old dug wells near by.

The catchment area is probably to the west or northwest, but the head may well be derived from the ground water in the slight ridge which lies only a short distance to the west. It is probable that this terrace at other points would yield flows from the same waterbed. Indeed for many years there was a small flowing well at the schoolhouse, across Pine River, in the northwest corner of sec. 17, which has now ceased flowing.

Water is reported to rise a considerable distance in tubular wells to the west and south, and in the "great swamp" district in this township some of the wells were said to have flowed at one time. These, however, have gradually lost head, until now the water stands 3 to 4 feet below the surface.

In this township the banks of the river have many places in which seepage springs occur at the junction of gravel and underlying clays. These springs are generally very small and unimportant. By the roadside in a stream valley, near the east and west quarter line of secs. 5 and 6, is a larger springy area, which, if it were developed and a basin provided, would yield a good supply of water for stock.

Wells southwest of Alma (sec. 8, T. 11 N., R. 3 W.).

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*		
John Wolf [a]	1902	2	41	755	+6	0.5	.....	Not very hard	Gravel.
John Wolf [b]	1902	2	41	755	+6	.5	52.2	do	Do.

[a] Inclosed in house. [b] Barnyard well.

SEVILLE TOWNSHIP.

RIVERDALE.

Riverdale is situated in the broad flat valley now occupied by Pine ver, and is only a few feet above the level of the river. The soil is rse gravel, underlain at from 3 to 6 feet or more by a stiff blue clay. Wells are generally from 23 to 26 feet deep, the shallowest 16 and deepest 100 feet. The water comes from a gravel stratum, and s in the pipes nearly to the surface. A few wells in low places are wed to flow into basins, and the water is then dipped or pumped. Strong's hotel is a well 52 feet deep, in which the water rises from bottom nearly to the surface.

It is evident from the above that at the lowest points in the town water would rise above the surface. Indeed, one such well at yant's mill, nearly three-fourths of a mile south of town, in the V. ¼ sec. 6, Sumner Township, flows at an altitude of 790 feet. is well is reported to be 25 feet deep. It used to flow about 1½ t above the surface, but in dry weather lowered a foot, the supply sening from 2 or 3 quarts to 1 quart a minute. The temperature 51° F. The well was bored in 1903, and the following beds were sed through:

Record of well at Bryant's mill, near Riverdale.

	Thickness.	Total.
	Feet.	*Feet.*
vel	12	12
clay	9 or 10	21 or 22
vel	3	24 or 25

There are several possible sources for public supplies: The river, ich in the region north and west of Riverdale is a spring-fed eam flowing through a thinly-settled country, should furnish good supply of pure water. Several brooks, fed by springs, near enough to be considered, and would be more easily pt free from contamination than the river, because of smaller ainage areas. Mud Lake, a small lake near the town, should give a od supply of water in spite of its name, because of its situation and e amount of water which flows out of it. There are many strong rings within short distances of the town, and careful investigation ight easily develop a good supply from this source. There is a very ringy track a short distance south of town, across the river, which ould furnish an abundant supply of pure water by enlarging the tlets and constructing artificial basins. A series of large tubular lls might be put down in the lowest part of the town, or a large tern might be built down to the water-bearing stratum which most the private wells reach, and a sufficient supply be obtained.

ELWELL.

This village in the northwestern part of the county has wells c from 14 to 26 feet deep and tubular wells to 40 feet deep. Seve tubular wells get a good supply of water in gravel below clay at feet. The water is hard and rises to within 4 to 8 feet of the surfa The average depth of 17 wells is 23 feet, the deepest being 27 f and the shallowest 14 feet.

NORTH OF ELWELL.

About 1½ miles north of Elwell there is a flowing well area, wh lies on the south side of secs. 23 and 24, near the foot of the sou easterly slope of a high and gravelly morainal ridge, which here r northeast and southwest. This ridge is the probable catchment a

There are two wells now flowing and three others in the area wl were reported to flow when in order. One of these, a dug well, purposely been partly filled to prevent the strong overflow and is pumped. The flows were small with slight head, and the wat obtained from a depth varying from 9 to 110 feet, the supplies s ing very irregular in their distribution. The water is of me hardness and rather free from iron. The table below gives the relating to these wells.

It might be possible to extend the area to the south of the pr wells if the water-bearing strata continue in that direction, as s probable. No wells in that part of the town flow at present; this is probably because they do not go deep enough.

Three large springs in this vicinity were pointed out by Mr. Wı Pitt, whose interest in this survey is highly appreciated. O these, on the farm of Mr. George Sandel, in the SE. ¼ SW. ¼ sec. estimated to flow about 50 gallons a minute. The water boil from coarse sand and gravel in the bottom of a shallow basin flows off in a considerable stream. It is used only to water s The second of these springs is really a group of considerable si the farm of Henry Carl, situated in the NW. ¼ NW. ¼ sec. 26. are "mound springs," built up of calcareous tufa to a height of a 2 feet above ground level, from which height the water now is The outflow from these springs is at least 50 gallons a minute, ably much more, running off through many small channels.

The third "spring" is apparently a very shallow flowing well to supply water for a portable sawmill. It is on the farm of Sadler in the NW. ¼ sec. 34. The outlet is about 3½ feet s through 4 feet of clay to coarse gravel, with no attempt to wall i The water runs in at the bottom of the hole about 8 feet belo surface in a swift-flowing stream and overflows in an outlet 16 i wide and 2 inches deep. It is now used only to water stock wh the pasture.

The water from all of these springs is cold and clear, quite hard, d with no large amount of iron present.

Wells north of Elwell (T. 12 N., R. 4 W.).

Owner.	Driller.	Cost.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
G. F. Taylor [a]	Chivers	$35	1895	2	50	775	+0.5	0.12	51	Hard; iron	Gravel.
Levi Hall [b]	Owner			1.5	9	778	+2				Sand.
S. Anchovy [c]	do	20	1900	2	32	775	+1			Hard; iron	Do.
L. Small	Chivers	85		2	113	775	+1	.25	50	do	Do.
E. A. Dailey [d]	Owner				14	780	0			do	Gravel.
A. Sadler [e]			1902	8		785	+50 75			do	Do.

[a] Hard clay from 2 feet below surface; sanded up.
[b] Not flowing at present because of loose casing.
[c] Said to flow 8 to 10 gallons a minute; now stopped by sand.
[d] Dug well; flowed a large amount formerly, but was partly filled at the bottom, and is now pumped.
[e] Called a spring.

PINE RIVER TOWNSHIP.

FLOWING-WELL AREAS.

Aside from the development of flowing wells in Alma and St. Louis, ›th of which were originally partly in Pine River Township, there 'e five small areas of flowing ells in the rural parts of the wnship which probably may › considered as independent of ıe another and of those in the wns, since they are getting ıter from different depths, and e separated from one another to well-marked and distinct ısins by low ridges.

FIG. 43.—Sketch map of flowing-well district in areas 1 and 2, Pine River Township, Gratiot County.

Area No. 1.—The first area ee fig. 43) is in a shallow, rather ırrow, poorly drained valley, 2 iles north of Alma, running ›m the east side of sec. 20 utheast and then east toward ne River. The valley extends farther to the northwest, but no wells ere reported in that part of it, possibly because it is not yet fully ıder cultivation. The area developed is less than 2 square miles.

The wells are shallow, from 15 to 30 feet deep, bored or driven, and ıve slight head, which has already been lowered by increasing the ımber of wells and allowing the water to waste. The wells number ›out a dozen. The largest flow is that of George Weeks (No. 1),

and the shallowest 14 feet.

NORTH OF ELWELL.

About 1½ miles north of Elwell there is a flowing we
lies on the south side of secs. 23 and 24, near the foot
easterly slope of a high and gravelly morainal ridge, w
northeast and southwest. This ridge is the probable ca

There are two wells now flowing and three others in t
were reported to flow when in order. One of these, a
purposely been partly filled to prevent the strong overfl
pumped. The flows were small with slight head, and
obtained from a depth varying from 9 to 110 feet, the
ing very irregular in their distribution. The water
hardness and rather free from iron. The table below
relating to these wells.

It might be possible to extend the area to the south
wells if the water-bearing strata continue in that direc
probable. No wells in that part of the town flow at
this is probably because they do not go deep enough.

Three large springs in this vicinity were pointed out b
Pitt, whose interest in this survey is highly appreci
these, on the farm of Mr. George Sandel, in the SE. ¼ S
estimated to flow about 50 gallons a minute. The w
from coarse sand and gravel in the bottom of a shall
flows off in a considerable stream. It is used only to
The second of these springs is really a group of consid

The water from all of these springs is cold and clear, quite hard, .d with no large amount of iron present.

Wells north of Elwell (T. 12 N., R. 4 W.).

Owner.	Driller.	Cost.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
G. F. Taylor [a]	Chivers	$35	1895	2	50	775	+0.5	0.12	51	Hard; iron	Gravel.
Levi Hall [b]	Owner			1.5	9	778	+2				Sand.
S. Anchovy [c]	do	20	1900	2	32	775	+1			Hard; iron	Do.
L. Small	Chivers	85		2	113	775	+1	.25	50	do	Do.
E. A. Dailey [d]	Owner				14	780	0			do	Gravel.
A. Sadler [e]			1902	8		785	+50 / 75			do	Do.

[a] Hard clay from 2 feet below surface; sanded up.
[b] Not flowing at present because of loose casing.
[c] Said to flow 8 to 10 gallons a minute; now stopped by sand.
[d] Dug well; flowed a large amount formerly, but was partly filled at the bottom, and is now pumped.
[e] Called a spring.

PINE RIVER TOWNSHIP.

FLOWING-WELL AREAS.

Aside from the development of flowing wells in Alma and St. Louis, both of which were originally partly in Pine River Township, there are five small areas of flowing wells in the rural parts of the township which probably may be considered as independent of one another and of those in the towns, since they are getting water from different depths, and are separated from one another into well-marked and distinct basins by low ridges.

FIG. 43.—Sketch map of flowing-well district in areas 1 and 2, Pine River Township, Gratiot County.

Area No. 1.—The first area (see fig. 43) is in a shallow, rather narrow, poorly drained valley, 2 miles north of Alma, running from the east side of sec. 20 southeast and then east toward Pine River. The valley extends farther to the northwest, but no wells were reported in that part of it, possibly because it is not yet fully under cultivation. The area developed is less than 2 square miles.

The wells are shallow, from 15 to 30 feet deep, bored or driven, and have slight head, which has already been lowered by increasing the number of wells and allowing the water to waste. The wells number about a dozen. The largest flow is that of George Weeks (No. 1)

which flows 6 gallons a minute. The water is medium hard, with some iron.

The catchment area most probably lies in loose-textured morainal ridges either to the north or south of the area, but may possibly be in a more extensive district of rolling country to the west and north.

Conditions seem favorable for flows in the upper part of the valley, northwest of the present development, especially if the larger flows now running are reduced to conserve the supply. It is not probable that flows would be obtained from this water-bearing level on much higher land than that on which the present wells are located, because, as noted above, the head has already been lowered 3 or 4 feet by the existing development.

Area No. 2.—This second area (see fig. 43) is less than a mile north of No. 1, along and north of the line between secs. 21 and 22. It lies in a shallow valley between low ridges; covers less than one-half a square mile, and contains only three wells, two of which now flow. These wells might be considered a part of area No. 1, and possibly they come from the same stratum, but they are at a slightly higher level, and it was reported that they are considerably deeper, except that of Mr. Mills, although this statement could not be verified.

FIG. 44.—Sketch map showing approximate position of the flowing wells in areas 3 and 4, Pine River Township, Gratiot County.

This area is not likely to be extended, because it already includes the area below the level of the head. The wells to the north for some distance are reported as having the water rise to within 5 or 10 feet of the surface. It is probable that one or both of the low ridges bordering the valley supply the water for this flowing-well area.

Area No. 3.—The next area is 3 miles north and 1½ miles west of St. Louis (fig. 44), and about the same distance north and east of area No. 1. It lies in a shallow depression which is the head of a drainage valley opening out to the south. Low hills of clay and gravel surround it on the three other sides. Like No. 2, this area is small—less than one-half a square mile in extent—and includes only seven wells, reported as varying in depth from about 15 to 42 feet. The flows are all of more than average size, ranging from 1 to 4 gallons a minute, of hard water of good quality. The head average from 1½ to 3 feet or more, although most are cut off about 2 feet above the surface. Just east of the area is a pump well at the school house, which was reported to be 120 feet deep, the water not rising very near the surface.

ground level rises rapidly in all directions, except to the
is is the only direction in which further development may
and here only near the bottom of the valley.
ly the ridges lying to the north and west of the area furnish
for these wells, but it may come from the more porous areas
est.

'o. 4.—The fourth area (fig. 44) contains a single well about
ep belonging to Mr. W. J. Brooks, which flows in wet sea-
not in dry. It is located in a depression, and lies about a
e northeast of area No. 3, and may possibly derive its water
of the strata which the wells in that area strike, but there
ridge between the two areas and they are best considered

'o. 5.—This is a fifth area with a small group of wells 2½
t and 2 miles north of Alma, and 1½ miles west of area No.
g only one-eighth of a square mile as at present developed.
are located on the slope of a stream valley, bordered on
and west by a low ridge with a sandy slope. At the time
ly two were flowing; the other had recently failed and had
ipped with a pump. The well with the best flow (Whit-
ll) was near the foot of the slope, and was flowing 5 gallons
of excellent, nearly soft water, with a head of about 5 feet.
eems to be no reason why this area should not be extended
d along the stream valley if the water-bearing stratum holds
at direction, for the slope is favorable, and other conditions
ally so. The catchment area is probably in the higher land
rth and west.

ry.—The flowing table contains data of the Pine River
ells, arranged by areas:

Wells in Pine River Township (T. 12 N., R. 3 W.).

AREA NO. 1.

No. on figs. 43 and 44.	Section.	Owner.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
			In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
1	28	Geo. Weeks	2	26	762	+2	6	48.5	Hard; iron	Gravel.
2	21	W. Lentz[a]	2	14	765	+3	3	49	Not very hard.	Do.
3	21	N. Johnson	2	16?	768	+1	2	48.8	Hard	Do.
4	27	Gordus Smith[b]	2	25±	765	+ .5	.25	49	do	Sand.
5	27	do	2	25	764	+ .5	.12	49	do	Fine gravel.
6	27	do	2	25	763	+1	.25	49	do	Do.
7	28	John Fafty	2	25±	764	+ .5	.25		do	Sand.
8	28	do	2	25±	765	+ .5	.5		do	Do.
9	28	E. Wilkinson	2	20+	760	+2			do	Gravel.
10	27	H. E. Kirby[c]	2	195	763	+2			do	
11	26	F. C. Olmstead								

AREA NO. 2.

1	21	T. J. Clark	2		770	+0	2	49.5	Hard	Gravel.
2	22	C. Sloane	2		770	+1	.5	49	do	Do.
3	15	D. Mills[d]	2	30±	772	+1				

AREA NO. 3.

1	2	A. Walls	2	50±	760	+1.5	1.5	49	Hard	Gravel.
2	2	C. A. Kiter	2	42	760	+2	3.5	49	do	Do.
3	11	S. Porter	1½	33	758	+2.5	4	49	do	Do.
4	11	G. W. Musser[e]	2	157	756	+2	3	49	do	Do.
5	2	Barton Bailey	2	18	760	+2.5	2	51	do	Do.
6	2	do	2	20±	760	+2	1	49	do	Do.
7	2	do	2		762					

AREA NO. 4.

1	1	W. J. Brooks[f]	2	40±	770	+1				

AREA NO. 5.

	30	N. Whiteraft	2	33	760	+5	5	49	Rather soft; iron.	
	30	do	2	80	760	-3				
	30	Daniel Wood	2		765	+ .5	1	49	Hard.	

[a] A 25-foot well on this place stopped flowing when this one was made.
[b] Pumping these wells affects all of them; head has lowered 6 to 8 feet.
[c] Said to have struck flow at 25 or 30 feet, but to have been deepened to present depth in hopes of getting a larger flow.
[d] Used to flow, but does not now.
[e] Flows from old pump log in two streams. Evidently old, but has good flow into ditch.
[f] Has a small flow in wet seasons, but does not flow in dry.

FOREST HILL

This village, on the Ann Arbor Railroad north of Alma, has wells from 18 to 20 feet deep, and drilled wells 80 to 150 feet deep, reaching rock. The water is hard, and rises within 20 feet of surface.

BETHANY TOWNSHIP.

ıis township lies in the north-central portion of Gratiot County, east of Pine River Township, and is almost wholly east of the ıinal ridges and is, therefore, free from the roughness of surface ent in the rolling portion of the county.

ST. LOUIS.

he greater part of this city is on a flat gravelly terrace, which forms bottom of the valley along Pine River, and which is 20 feet or more ve the stream. The sides of the valley are morainal ridges, and e are occupied by part of the residence portion of the city.

public supply was formerly obtained from a group of three or four ing wells at the level of the mill pond, near the north end of the cipal street, but because of a partial failure of these, due to the ustation of the sand screens by calcareous matter deposited from water or to sand clogging, or both, they have been abandoned, and water now used in the town is pumped from the mill pond. This sed for sprinkling, fire protection, etc., and not for drinking.

[ost of the flowing wells, which were said to derive their water n 50 to 75 feet below the surface, ceased to flow when the water-ks wells were put down. Many were abandoned; a few were pened and the flow resumed; and some were furnished with ıps. Dug wells range from 15 to 40 feet in the clay on the ridges, tubular wells have been drilled to various depths, some even hing the rock at 325 to 350 feet.

t. Louis has long been famous for its "Magnetic Mineral Spring," ch for thirty-five years has been pouring out its waters. This is a ing well 270 feet deep, situated on the bank of Pine River near the l of the water and has a head about 16 feet above the river. It s a large amount of water, but from the way in which it was piped estimate could be made of the amount of flow. The water is used baths and various other purposes at the sanitarium near by and n 15,000 to 18,000 gallons are sold and shipped to Saginaw each k and a considerable quantity to Chicago. This well also supplies rge number of the people of the town with drinking water for table , for which purpose it is supplied free of charge. It is sold at $5 a barrel of 30 gallons, with a rebate of $2.50 when the barrel is ırned to the shipping point. It is also shipped in cases of 50 ırts, carbonated, at $5 a case.

ı few other private wells in the town flow at the present time, and , at least, of the old waterworks wells is still open, the water run-g to waste.

The following record of one of the wells at St. Louis was gathe by Alexander Winchell:

Record of drift well at St. Louis.

	Thickness.	Tot
	Feet.	*Fe*
Clay, gravel, and bowlders	40	
Blue clay	30	
"Fire clay"	13	
Sand and gravel	39	
Bluish indurated shaly clay	15	
Sand and gravel	55	
Pebbles, water	8	
Rock (not positively).		

There is a chemical manufacturing plant in the city which deper on deep drilled wells for the brine from which it obtains its produ No data could be obtained regarding these wells, as the plant was i in operation.

Wells at St. Louis.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Wa be
		In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		*Feet.*	
Doctor Andrews[a]	1869	4	270	725	+16	10?	52	Hard; iron	350±	Gra
M. Hoffstetter		2	60	730	+ 1	.12	52	Hard	350	D
J. A. Burgess		2	45	730	+ 1	.12	51	do	350	D
City waterworks[b]		6		725	+ 2	3	52	do	350	D
East of Harrington Hotel[c]		2	40±	733	− 2	1		do	325	D

[a] Waters, "magnetic;" used externally and internally as remedy for diseases. Sanitarium in co tion. Water shipped to sell in cities.
[b] Only waterworks well now flowing. Flow is through a hole in the cap of the casing.
[c] Flows into tank 2 feet below surface.

BRECKENRIDGE.

This village is situated on a slight gravel ridge 6 miles east of Louis. The depth of the wells is very variable, according to t nearness to the gravel tract. On this tract dug wells are from 8 t feet deep and driven wells 16 to 20 feet. Away from the gravel the driven wells are much deeper (some between 100 and 200 deep), while one hole in the village was visited which was 208 deep and had no water. At this well there was 15 feet of ra porous surface material with a small supply of water, and then feet of compact clay, below which the material was variable, chiefly clay with stony streaks in it.

There are no flowing wells here, but A. W. Stone's well, 115 deep, was reported to have water to within a foot of the sur The water of this well has a strong taste resembling petroleu "much stronger after pumping, so the horses will not drink

the wells about 100 feet deep strike a large supply. The
ll of the wells but the one just referred to stands from 8 to 10
' the surface. Rock was not struck in the 208-foot well.
ɜ no system of public supply and no good prospect for suffi-
ɔly except from deep wells, unless a supply should be found
sand and gravel ridges lying north of the town a short dis-
hese serving as a catchment area should have considerable
ɔw them if the condition of the soil is favorable for hold-

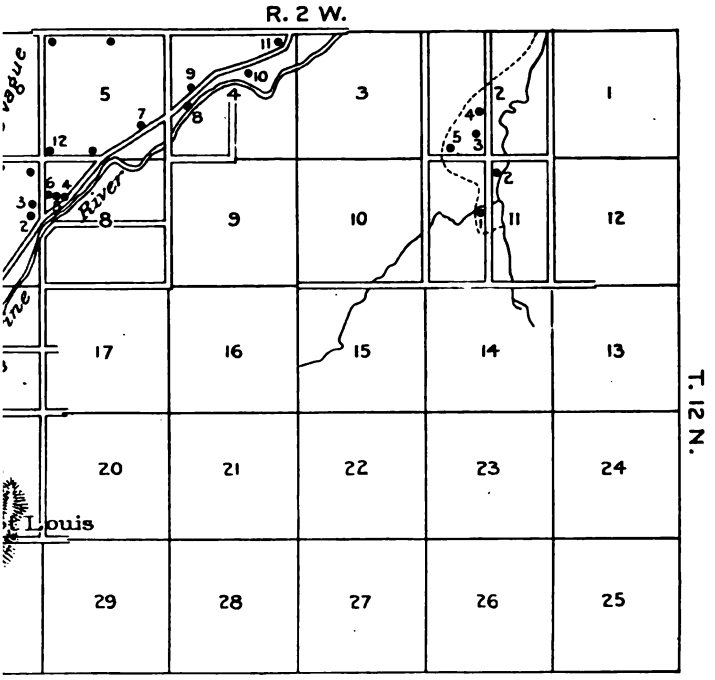


FIG 45.—Bethany Township flowing-well areas, Gratiot County.

WEST OF PINE RIVER.

the development at St. Louis, Bethany Township has two
ɪs of flowing wells separated by Pine River, one lying to the
the other to the east of the stream.
ɪt of these areas lies in the immediate vicinity and wholly on
ɪide of Pine River (fig. 45), extending down the river to the
ɪe from a point 1½ miles northeast of St. Louis. Its extent
ɪent developed is approximately 2½ square miles, in which
15 or more flowing wells. It is possibly continued into the
ɔt of southeastern Isabella and southwestern Midland coun-

The wells of this area, like some of the others studied, show considerable variation in depth, head, and size of flow, the deeper wells having the best supply of water, which is not always the case in this region, notably at Alma, where deep flows are small. The flows were reported to come from a number of depths—30 feet for the shallowest and about 100 for the deepest. As the surface is nearly flat, these probably represent variations in altitude of strata.

The most remarkable well is that of W. H. Fox, in sec. 4, about 3 miles northeast of St. Louis. This is located on the river terrace, is 86 feet deep, and is said to be 16 feet into the rock. It had a head of nearly 20 feet and was flowing the full size of the casing, at 4 feet above the ground, with such force that it was scarcely possible to fill a small vessel from it. The owner reported that the flow amounted to very nearly 3 barrels a minute, or more than 100,000 gallons a day, the greater part of which runs to the river as waste.

The water-bearing stratum was said to be 3½ feet thick, apparently, as it was described, an underground stream or basin below the rock. Small flows were struck at 45 and 56 feet. It is possible that the rock reported at this point is not a part of the underlying Carboniferous deposits, but a thick, hard bed of glacial material indurated by calcium carbonate, which acts as a cap stratum to confine the water. At St. Louis rock is reported at from 332 to nearly 400 feet below the surface.

The catchment area for the majority of these wells is the higher country to the west and north. If the Fox well is really in bed rock, the water may still come from the drift, working into the rock from the sides of exposed strata where these have been eroded.

As the land rises quite rapidly to the west from the river, there is no probability of extension of the flowing-well area in that direction, and as it was reported that no flows had been struck on the east side of the river, although there were some deep wells, it seems possible that no extension can occur there, because of the slightly higher level of the land. To the north along the river and at low levels generally the chances of getting flows in this area seem excellent if the wells are made deep enough.

EAST OF PINE RIVER.

The other area (fig. 45) is 3 miles north and 2 miles west of Breckenridge, or 2½ miles east of the first. It is in the northern half of sec. 11 and the southern half of sec. 2 in the scarcely perceptible valley of a small stream flowing northeast to Pine River.

The entire area as developed is less than a square mile in extent and contains but five wells, which are from 65 to 75 feet in depth, with slight head and small flows of hard water, the largest flow being but 2

llons a minute. The Holton well (No. 4) is reported by the owner receive most of its water from a fine sand at a depth of 35 feet. The catchment area is probably the higher land to the west of the er, and the stratum from which the water comes may be an eastrd extension of one of the upper strata of the western area. There no evidence to demonstrate this, however, because of the lack of nsecutive borings between.

The flows from the strata already reached seem to be limited to the allow depression made by the stream; hence development of flows er a much larger area is not probable, except near the bottom of the ek valley to the northeast of the present area.

The wells on the east side of the creek which reach down to the depth this stratum do not flow, but the water rises to within a few feet of e surface, the land being slightly higher than that on the west side.

SUMMARY.

The facts relating to the wells of this area appear in the table below:

Wells in Bethany Township (T. 12 N., R. 2 W.).

WEST OF PINE RIVER.

	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
1	7	W. H. Walland [a]	1895	2	30	740	+2	.....	.....	Hard; iron	Gravel.
2	7	Noah Wilson [b]	1897	2	100	740	+2.5	15	49.5	.....do....	Rock?
3	7	Noah Wilson	1894	2	100?	735	+3	.25	.....	.....do....	(?)
4	8	Mrs. E. Shook [c]	.....	1½	80	743	+2	.75	50.5	.....do....	Gravel.
5	8	Mrs. E. Shook	.....	1½	50	735	+2	.12	.....	.....do....	Do.
6	8	.....do	.....	1½	50	733	+2.5	.25	50	.....do....	Do.
7	5	P. D. Smith	.....	2	86	740	+2	.5	51.5	.....do....	Do.
8	4	W. H. Fox [d]	1904	3	86	730	+18	100	50	.....do....	Rock?
9	4	F. Quidart	.....	2	85?	740	+2	8	50	.....do....	
10	4	C. H. Colbey	.....	2	100	735	+3	10	.....	.....do....	
11	4	F. Peach	.....	2	100	738	+2	5	.....	.....do....	Gravel?
12	5	Lydia Crawford [e]	.....	....	40	745	+1	.....	.....	.....do....	Gravel.

EAST OF PINE RIVER.

1	11	D. D. Gidley [f]	1900	2	75	740	+1	0.5	52	Hard; iron	Gravel?
2	11	S. M. Barnes	1902	2	65	738	+2	1	50	.....do....	Gravel.
3	2	A. Gidley	1900	2	68	733	+1	.33	51	.....do....	Do.
4	2	Harvey Holton [g]	1902	2	65	730	+1.5	.2	51	.....do....	Sand.
5	2	Jas. Hearne [h]	1904	2	65	735	+.75	2	49.8	.....	

[a] Flows a few drops a minute; formerly flowed much more.
[b] Said to be in rock, but doubtful.
[c] Piped to house; No. 5 is in pasture, and No. 6 at barn for stock.
[d] Said to be from rock at 70 feet, hard rock at 78 feet. Flow said to be about 3 barrels a minute, but force too great to be measured with anything at hand. Water also at 45 and 56 feet.
[e] Flows into cistern and is dipped out.
[f] Cut off below surface and flows inside of gully. Will flow above surface at mouth.
[g] Cased 27 feet; water from 35 feet; used to flow more but filled in with sand. Hard smooth clay with few stones all the way down. Water from fine sand under crust of hardpan.
[h] Drill dropped 3 feet when water was struck. Cost about $45.

ELBE TOWNSHIP.

BANNISTER.

Bannister is situated in a very flat region on the bank of Maple in the southeast corner of Gratiot County. The soil is a heavy pact clay loam, hence it is not very porous and lets in very water, now that the drainage has been so highly developed, and fore the shallow ground-water supply is poor and small.

There are, as in many villages, shallow dug and bored wells fr to 25 feet deep. In the western part of the town it was reporte a bed of gravel 16 to 18 feet below the surface furnishes a smal ply of water, usually enough for family purposes, but the sh dug, open wells, are not ir repute, and tubular fl wells scattered over the now furnish the greater p the potable water used.

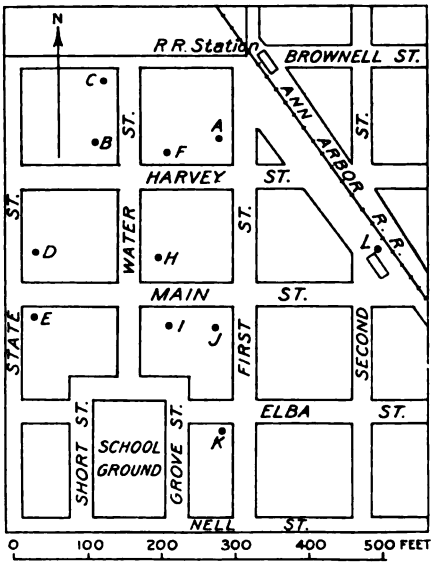


FIG. 46.--Plat of village of Bannister, Gratiot County.

The drift clays and g are reported to be abou feet thick in the village the predominance of compact stony clays mak difficulty of getting fl water from the drift ver siderable, but there ar wells which are certainly the rock, and others are ably of this type. The acteristics of these wel shown in the accompa table. The water from tl rather hard and contains but is as good as the waters from the drift usually are. The flo rather small, with slight head. Wells here of this class are more apt to fail than those from the rock, and the present ten in the village seems to be to drill to the latter for water.

These wells are numerous in the village and surrounding co and are of varying depths, those of the village generally being re to be more than 200 feet deep. They enter rock at about 15 The deepest reported was 390 feet, probably a mistake, and the lowest about 200 feet. The flows from the rock are generally and with more head than those from the drift.

In case the town desired a public water supply, it could be pu directly from Maple River for fire protection and other general

d its potable water be secured from private flowing wells from the ck.

The cost of putting down wells in this locality is 75 cents a foot for illing and casing, if a pump is required, but the drillers often hire out th their machine by the day, and the owners of the prospective wells ay assist by their work or furnish casing themselves, thus reducing e cost of the wells materially.

Wells in Bannister.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
A. Evans	.....	2	50	688	+1	0.12	.....	Hard....	Gravel.
R. Russell [a]	.....	2	160?	688	+.5	1.25	50.5	Iron....	Do.
Mrs. Davidson [b]	.....	2	36	688	+1	.5	.....	....do...	Do.
D. Campbell [c]	1885	2	+90	688	+3	2.5	52	....do...	Do.
E. Weston [d]	.....	2	60	688	+6	.66	53	....do...	Do.
E. Bensinger [e]	.....	2	−550	690	+1	.....	.....	....do...	Do.

[a] May be from drift as suggested by low head.
[b] Now pumped from tank used for refrigerator.
[c] Piped underground.
[d] Piped underground 10 feet.
[e] Not flowing now but crocked above head and pumped.

ASHLEY AREA.

Ashley.—Ashley is situated in the southeastern part of Gratiot unty, in the flat bottom land which marks the bed of the Glacial ake Saginaw, which at one time covered the region. The site of the llage is a faint terrace, which extends northeastward some distance d which is elevated a few feet above the level of the land to the uth and southeast.

The soil here is a compact clay, which, previous to the clearing and tching, was covered with a heavy growth of swamp timber, and had upper layers saturated with the product of decay of the abundant getation. As a result of this type and condition of soil the waters ar the surface are impregnated with organic matter. The amount water was small, and as clearing progressed became smaller, so that allow dug wells were early found to be inadequate, going dry quickly d furnishing poor and unwholesome water.

Tubular wells were therefore resorted to, and deeper supplies of bet- r water were obtained, so that at present the majority of the people t water for drinking and domestic purposes from deep-drilled wells, hich reach down nearly to bed rock, or, in some instances, penetrate for considerable distances.

Wells in the rock frequently flow with a good supply of water, and all the rest the water rises nearly to the surface. The rock surface as reported to be from 100 to 120 feet deep in the village. The pub- c well, near the railroad station, is a good example of this class of

wells. It is 270 feet deep, about 170 feet in the rock, and the water flows 2 feet above the surface at the rate of 2½ gallons a minute. The water is of excellent quality, rather soft, and has a small amount of iron and other mineral matter in it. The overflow runs into a reservoir from which it may be pumped in case of need for use in protection against fires.

Within 150 feet from this well is a pump well, which was reported by the driller to be about 100 feet shallower but still deep in the rock, in which the water stands a few feet below the surface. When this well was vigorously pumped a very few strokes, the village well would cease flowing. This fact soon became a source of great annoyance to those using the flowing well on account of the temptation it afforded to play practical jokes, and after a time the authorities of the town purchased the pump well and dismantled it. This is an interesting case of transmission of change of pressure through considerable distances of rock very quickly. The raising of the water by the pump evidently reduced the hydrostatic pressure and buried the head sufficiently to stop the flow in the other well. This lowering of head manifestly need not be more than an inch or two, provided the outlet of the flowing well was about at the level to which the water would rise under the existing pressure.

One-half mile northeast of the village is a flowing well owned by Mr. Charles Kerr, which is reported to be about 600 feet deep. The water is strongly impregnated with mineral matter, the most noticeable constituents being hydrogen sulfid and salt. This water has been put upon the market, and is sold at the well at 1 cent a gallon. It is also used for mineral baths.

Aside from the few shallow dug wells, there are also in the village a few bored, driven, or drilled wells from 50 to 65 feet into the drift, the water having sufficient head to rise to within about 5 feet of the surface. Such wells are sometimes provided with a cistern of drain tile, from which the water is pumped.

The two partial analyses given below are from a deep sulphur well whose water is being bottled for medicinal purposes, and from a deep gravel well at Ashley, respectively. The analyses were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well waters at Ashley.

[Parts per million.]

	1.	2.
Color	15	10
Iron (Fe)	2.25	2.75
Chlorine (Cl)	384	29
Carbon dioxide (CO_2)	79.15	86.18
Sulphur trioxide (SO_3)	+522	353
Hardness (as $CaCO_3$)	+139	+139

S. J. Lewis, analyst. 1. Charles Kerr; depth 600 feet. 2. Village; depth 270 feet.

y of Ashley.—The country about Ashley, especially to the ıtheast, and southwest, has nearly the same soil character- he village, being, if anything, more swampy. Hence it has more necessary to get supplies of water from the deeper ·ata in the clay, or, failing in this, to go down to the sand- ıl shales of the coal measures lying still deeper. This neces- ·d to a large development of the deeper water-bearing strata, those in the bed rock, from which, in many cases, flows ı obtained in the east half of Washington and the south part ownship. (Fig. 47.)

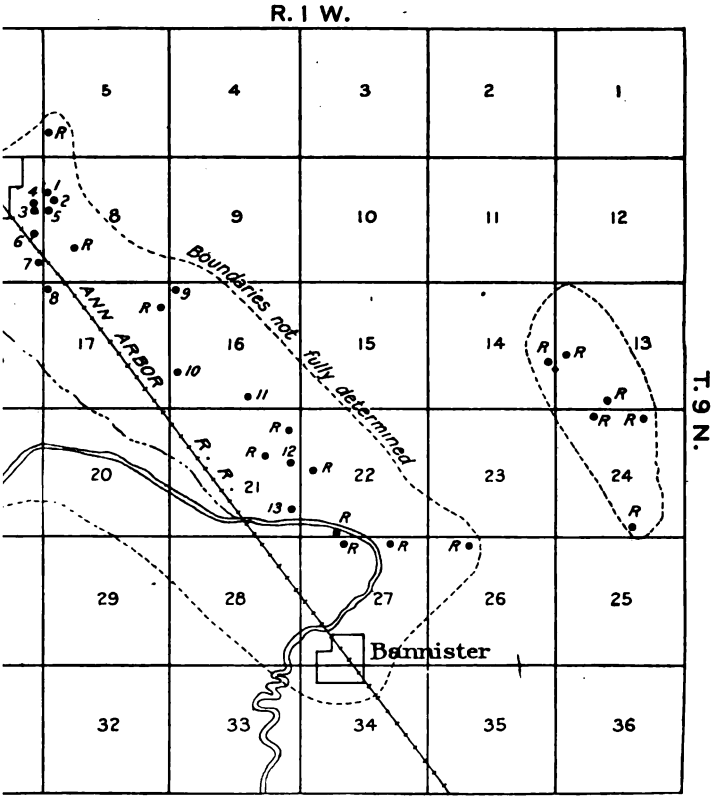


FIG. 47.—Ashley and Bannister flowing-well areas outside of village wells.

region has been carefully prospected for coal, many of the holes have been utilized for water. The usual arrangement hat the owner of the land shall have the hole for a well if struck, by paying for the pipe used in casing down to the ›me of the prospect holes, usually 4 inches in diameter, have .rge supplies of water with strong heads, but the owners have luced the flow to their needs rather than try to care for the ste in *the flat and not* easily drained region.

East and south of Ashley, on the broad flat below the terrace on which the town stands, is an area of shallow wells deriving supplies from the strata of sand and gravel in the clays. The shallowest flowing well reported was 14 feet deep, but otherwise the range was from 25 to 72 feet. The flows usually are quite small, and show a tendency to decrease. The head is 1 to 4 feet and the water is hard, with some iron in it.

The area as now developed is approximately 7½ square miles, all north of the river, and in general it does not seem possible that this can be increased much, except in the number of wells, for in the eastern part of the township the rock surface rises until in places it is covered by less than 25 feet of drift. In this region also the material overlying the rock changes from clay to gravel, and as this is not covered by a compact stratum, the water is dissipated and does not rise in the wells. To the north of the area the ground rises above the level of the head, so there can be no flows in that direction.

Much more extensive is the area over which flowing wells may be obtained from the rock. These occur both east and north of the area in which the drift flows are struck, and also throughout the eastern half of Washington Township. The water from the rock wells usually contains less iron and is less hard than that from the drift, and the supply is not so likely to fail, both because of the greater extent of the water-bearing strata, and because of the less danger from clogging from the action of the water on the pipes, the working in of sand, or the clogging of screens. Ultimately the greater part of the water used in this region will be obtained from wells drilled in the rock.

The sources of supply of this area may be, and probably are, in the gently sloping districts of considerably higher level lying north of the flowing-well area, where a large part of the rainfall is absorbed by the ground because of its loamy and sandy character, and finds its way very gradually to the lower levels, from which it is forced by the pressure behind it when a well tube finds its way into a more porous stratum than usual.

Summary.—If, as assumed, the area to the north is an important source of supply, the present policy of developing an elaborate system of ditches across the contours in this region must operate to reduce enormously the supply of ground water, and one can not but view with concern the present activity in seeking means to carry off water which should have a chance to soak into the ground. Cultivation, as commonly carried on, tends still further to decrease the supply of ground water, by hastening evaporation, and of decreasing the absorbing power by rendering the surface of the soil hard and nonabsorbent

Wells of Ashley area (T 9 N., R. 1 W.).

	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
			In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		*Feet.*	
5	E. J. Stratton [a]	1903	2	57	680	+2.5	4	50.3	Hard	150	Gravel.
8	E. J. Stratton	1885	2	.....	680	+0	8	50	Hard; iron	.....	Do.
7	Cyrus Stratton	1900	1½	45	678	+2	.5	50	...do	.....	Do.
7	....do	1900	1½	65	678	+3	.25	50	...do	.....	Do.
8	Chas. Green	.....	2	30	680	+1	.2	51	Hard	.....	Do.
7	Fuller & Lewis [b]	1895	2	30	680	+1.55	.12	.....	...do	.....	Do.
7	R. E. Parker	1895	2	25	676	+3	.25	.....	...do	.....	Do.
7	F. M. Baker	1900	2	47	680	+1	.12	51	Hard; iron	.....	Do.
6	J. Hasper [c]	.....	2	72	685	+1	3.5	.....	...do	±125	Do.
6	C. J. Brubaker [d]	.....	2	14	680	+1	±.5	.....	...do	.....	Do
6	Levi Smith [e]	.....	2	85	680	+1	.....	.....	...do	±120	Do.
1	S. R. Hubbard [f]	.....	2	55	680	+1	.25	52	...do	±133	Sand.
1	J. Sharp [g]	1894	2	72	685	+2	.25	52	...do	.....	Do.
1	Wm. Sharp	.....	2	50	685	+2	.5	52	...do	.....	Do.

ry little iron present; leaves granular scale.
kettle.
ll at brickyard; casing leaks badly.
ll flow 1 foot above surface, but is pumped.
[d] Will flow a small stream, but is pumped; bored.
[e] Will flow a small stream, but is pumped.
[f] Supply is decreased by clogged screen.
[g] Thought to be filling with sand at bottom.

MISCELLANEOUS VILLAGE SUPPLIES.

ITHACA.

haca, the county seat of Gratiot County, is situated in the exact er of the county, with no stream or pond in its vicinity. It is t upon a low morainal ridge, which slopes off to the east into a ıd plain and to the west into an extensive swamp. The moraine is of compact till or clayey gravel, and does not yield much er. On its slopes it becomes more sandy, and shallow wells here rather limited supplies.

he problem of a public water supply was settled two years ago by ing down a series of three 6-inch tubular wells 600 feet deep, ıgh 300 feet of drift, into the sandstone below, from which a sup- of hard but otherwise good water, which rises to within 50 feet of surface and is sufficient for present needs, was obtained. The er is used for all purposes, domestic, fire protection, sprinkling, boilers, and the supply is constant. The plant is a public one in ge of a water board.

he private wells are shallow, dug, open basins, or in a considera- number of cases tubular drilled wells, ranging from 50 to 90 feet). The water is hard and possesses the usual characteristics of er from the drift in this section.

BEEBE.

n the vicinity of Beebe, to the northwest of Ithaca, water is ained either from open dug wells 25 to 30 feet deep or driven ls 30 to 40 feet or more. The water rises within 10 feet of the

surface in some of these, and is hard, with considerable iron. It comes from gravel below rather stiff clay. There is a public well here, but nothing is known about it.

EDGEWOOD.

This hamlet, in the eastern part of the county, has dug wells 10 to 30 feet deep. The water is from sand or gravel, is hard, and rises within 6 to 10 feet of the surface.

ELM HALL.

This village lies in the shallow valley occupied by Pine River, which has here a gravel bottom. The wells are shallow, dug to the bottom of the gravel to abundant water at 12 to 20 feet below the surface. The deepest wells lying outside the valley are from 50 to 60 feet in depth. The water is hard and from gravel. Water for fire protection could easily be obtained from Pine River.

MIDDLETON.

Middleton, in the southern part of the county, has dug wells from 12 to 30 feet deep and driven wells 50 to 65 feet deep. A large supply of water, found at from 60 to 65 feet, is hard and rises within 10 to 15 feet of the surface. The wells in this vicinity are frequently bored with large augers, driven by horse power, and walled up with drain tile carefully cemented.

NEWARK AND NEW HAVEN.

These two hamlets, southwest of Ithaca, are well supplied with easily accessible water, usually reached by digging or boring from 20 to 40 feet and stoning or tiling up the sides of the well.

NORTH STAR.

This village, which is southeast of the county seat, has open or dug wells 12 to 16 feet deep and one drilled well, 214 feet deep, which obtains a large supply of water in sand and gravel at about 200 feet No rock was struck at this depth.

OLA.

This village, in the southern part of the county, has open well 12 to 30 feet deep and driven wells down to 60 feet. The wate rises within about 10 feet of the surface.

PERRINTON.

This village is on the banks of Pine Creek, a tributary of Maple ver, in the southern part of the county. The wells are from 12 to feet deep, either dug or bored and tiled. The water, which is ırd, is abundant, but does not rise much in the wells except in et seasons.

POMPEII.

This village, in the southern part of the county, has dug and ored or driven wells from 20 to 40 feet deep. There is no diffiulty in getting a plentiful supply of good, though rather hard, rater. There are no flowing wells in the vicinity. In North Shade 'ownship, west of Pompeii, the wells are generally dug 20 to 45 feet. Vater is plenty and easy to get. Around Brice post-office, in this ownship, wells are usually 16 to 30 feet deep, but a few are 45 feet. 'he water rises within 8 to 20 feet of the surface and is rather hard.

RATHBONE.

Rathbone, which lies in the eastern part of the county, has open vells ranging from 10 to 15 feet in depth, with water within 4 feet f the surface. Driven wells are reported as deep as 160 feet, with he water rising within 20 feet of the surface.

WHEELER.

This town is located on a plain in the northeastern part of the ounty, which is here covered with a shallow deposit of gravelly oam. Most of the wells of the village are very shallow, from 6 to 5 feet deep, dug or bored through the gravel to the underlying lay. Those on the clay soils are dug somewhat deeper. At from '5 to 28 feet there is plenty of water, though rather hard. The eepest well was reported to be about 80 feet deep. One-half mile ast of the village, on SW. ¼ sec. 22, Wheeler Township, there are ells 28 feet deep, in which the water rises within 9 feet of the surce, coming from a thick bed of gravel. In the vicinity of North 'heeler wells are often 60 feet deep, though some dug wells are ıly 12 to 14 feet deep.

WATER SUPPLIES OF MIDLAND COUNTY.

GENERAL STATEMENT.[a]

The examination of flowing wells in the western part of Midland ıunty was made by W. M. Gregory. In the original plan Mr. egory was to have covered the entire county, but the time at his mmand did not admit his doing so. Mr. Davis therefore gave

[a]By Frank Leverett.

such time as he could spare to this study, but it was scarcely sufficient to insure a thorough survey, and small districts in the northern part of the county were not visited.

It is probable that flows can be obtained along all the valleys in the county, and perhaps over wide areas between the valleys in the western half and the southeastern fourth of the county; the northeastern part is too high to expect flows. Much of the county is covered with sand, and wells are obtainable at its base at a usual depth of 20 feet or less. This fact and the sparseness of settlement accounts for the present limited development of flowing wells.

As in Saginaw County, the slopes are very gentle, and the catchment areas likely to be a little farther up the slope than the wells, rather than in some distant morainic ridge, though some water may be contributed from these remote sources. The very slight head is in keeping with the interpretation that the bordering parts of the sloping plain are the chief catchment areas.

SUPPLIES BY DISTRICTS.

LARKIN TOWNSHIP.

About 4 miles north and 1 mile west of Midland, lying along the shallow valley of a small tributary of Tittabawassee River, is a group of ten flowing wells, which differ from those of the other areas in Midland County in yielding water which is noticeably brackish.

These wells are from 45 to nearly 80 feet deep, the deeper ones occurring at the north and the shallower ones at the south end of the area. It is probable that the water comes from two or possibly three different strata. The flows are all of very moderate or small size, the largest being only about 2 gallons a minute. The head is slight, the maximum reported being only 5 feet.

This part of Midland County is a region of salt springs, some large ones existing in the valley of Tittabawassee River, a few miles west of this flowing-well area. These probably owe their origin to fissures in the bed-rock, extending down to the salt-bearing coal measures, or to the deeper Marshall sandstone. The salt water from these formations, which rises in salt wells nearly to or above the surface, in passing through the unconsolidated clays and gravels above the rock surface, would spread out in the more porous strata, and give a brackish taste to the water already present. It might also be true, in some cases, that the brine would find its way directly upward from the fissure into a bed of sand or gravel and spread laterally for a long distance without breaking out at the surface at all. An interesting feature of these wells is that those which are shallow are rather more brackish than the deeper ones, a fact that would lead to the conclusion that the water comes from different strata, since the

ne would naturally sink to the lowest part of the stratum t occurs, leaving the lighter mixed waters above.

ssible that the deposits above the bed rock may have been rived from salt-bearing rocks, and that this material now brackish taste to the water. The limited area over which ish water occurs, its nearness to known salt springs, and the story of the sands and clays from which the water comes, favor the first theory.

lls to the west of the present development which are deep reach the water of these strata do not flow above the surough the water rises in some of ly to it, and if especial care were ind depressions in which to locate flows might be secured for a mile to The area might also be extended tream, both north and south, if the ch yield the water are present. As untry in these directions is not dend nothing is known of the extent er-bearing strata.

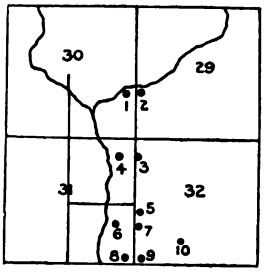


FIG. 48.—Sketch map of Larkin flowing-well district, Midland County.

stion of the wholesomeness of salty h waters is often raised, and while r is not absolutely settled, the consensus of opinion seems slightly salt waters are not in any way injurious to health. probably should be accompanied by a lessened use of salt ing food, and in this way the salt ration kept from running as excess of salt undoubtedly has an irritating effect on the organs.

lowing table and the sketch map (fig. 48) give the data o these wells and show their approximate position with the stream. The address of well owners and drillers is

Wells of Larkin Township (T. 15 N., R. 2 E.).

No. on fig. 48.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	30	G. W. Stearns [a]	1904	2	79	±625	+2	0.25	49.5	Brackish	Sand.
2	29	J. Putnam	1904	2	±75	±625	+1½	.12		do	Do.
3	32	R. Blaine [b]	1904	2	73	±625	+4	2	49.2	Brackish; bitter.	Gravel.
4	31	Geo. Jennings	1895	2	70	±625	+2	.25	49.8	Brackish	Do.
5	32	J. Cole [c]		2	±60	±620	+2	.12	52	do	Gravel.
6	31	W. Adams	1903	2	45	±625	+ .5	2	51	Hard; salty.	Gravel.
7	32	E. Town [d]	1901	2	±60	±625					
8	31	Ed. Caldwell [e]	1897	2	±50	±620	+3	1.5	49.2	Hard; slightly brackish.	Sandy gravel.
9	32	G. B. Weidemann	1897	2	±45	620	+1	2	49	Hard; slightly brackish; iron.	Gravel.
10	32	do		2		620	+2	.12			

[a] In barnyard. House supplied by seepage spring on bank of stream.
[b] Clay all the way down to gravel.
[c] Used for cooling milk, etc.
[d] Head near surface; flows small amount into underground reservoir from which it is pumped.
[e] Used in cooling milk.

MIDLAND TOWNSHIP.

MIDLAND.

The town of Midland is situated in the southeastern part of Midland County, on the banks of Tittabawassee River, at its junction with the Chippewa, which comes in from the west, shortly after uniting with Pine River from the southwest. The larger part of the town is on the north bank of the river valley, 35 or 40 feet above the low-water level of the stream.

The bank rises in a series of rather narrow terraces, the highest being a sandy ridge, which is probably part of a shore line of the Glacial lake which covered this county. The south bank of the river is much lower, and a broad flat terrace, the bottom of what may have been formerly a wide estuary or narrow bay connected with the lowest level of the Glacial lake, stretches away to the south for more than a mile before the south side of the valley is reached. Outside this broad shallow valley and others similar in origin, the greater part of Midland County is very flat, the soils varying from heavy clays to light wind-blown sand. The principal relief forms, as elsewhere on the "lake plain," are sand or gravel ridges which wind across the plain irregularly, forming low lines of elevations above the general surface. The plain in the vicinity of Midland is especially flat, and the river here is but a very few feet above the level of Saginaw Bay. There is a gradual rise of a few feet to the mile toward the west, northwest, and north. The whole county is exceptionally well watered by surface streams.

The town of Midland has a public water supply, the pumping sta-
n of which is situated on the lower river terrace, on the south side
the river near the point of union between the two streams. For-
rly the supply was obtained from driven wells which flowed above
surface, but now it is drawn from the Chippewa River at its junc-
n with the Tittabawassee, the wells having failed to give an ade-
ate supply. The Chippewa is fed by springs along its entire course,
d flows for a long distance through a practically uninhabited coun-
, as does its tributary, the Pine, but the growing cities of Mount
easant, on the Chippewa, and Alma, and St. Louis, on the Pine, all
n their entire sewage into these streams, which ultimately will thus
come highly polluted. At present the water is generally used for
nking and all domestic purposes, as well as for fire protection, etc.
The wells of the higher part of the town are generally dug or driven
m 12 or 15 to 30 feet. The sandy upper stratum of the soil in this
rt of town is underlain, at a relatively short distance below the sur-
e, by a compact clay on top of which it is usually easy to get water.
ch shallow wells as are thus obtained, more especially the dug wells,
the more thickly peopled parts of town should be looked on with
spicion on account of the ease with which they may be contaminated
m cesspools and outhouses. Driven wells from 25 to 200 feet or
re deep are, however, frequent, and to these there can be no objec-
n as sources of domestic supply. The deeper wells give the best
pply of water, which, however, is often a trifle brackish and which
es in the casing to within a few feet of the surface.

On the north side of the river only two flowing wells were found
thin the town limits, and these were both in the river valley some
stance below the general level (fig. 49). This seems to indicate that
e head of the numerous flows on the south side of the river is not
fficient to raise the water to the height of the north bank. On the
th side of the river, within the limits of the town, are many wells
ich flow. These are generally from 100 to over 200 feet deep, and
e strongest have a head of 16 to 18 feet. The largest flows are from
to 22 gallons a minute, while the smallest ran but a thread of water.
e Burt farm, on the lower terrace of the river, on sec. 21, has one
the most powerful wells, flowing more than 20 gallons a minute
th a strong pressure. It was reported that in putting down the
ll small flows were struck at four levels above the one from which
present supply is obtained.

The water from the deeper flowing wells is nearly free from hard-
s, as is that of some of the shallower ones, and in many cases is
htly brackish. The salt probably comes from the neighboring
wells, from some of which the brine may have leaked into the
ds and gravels of the drift.

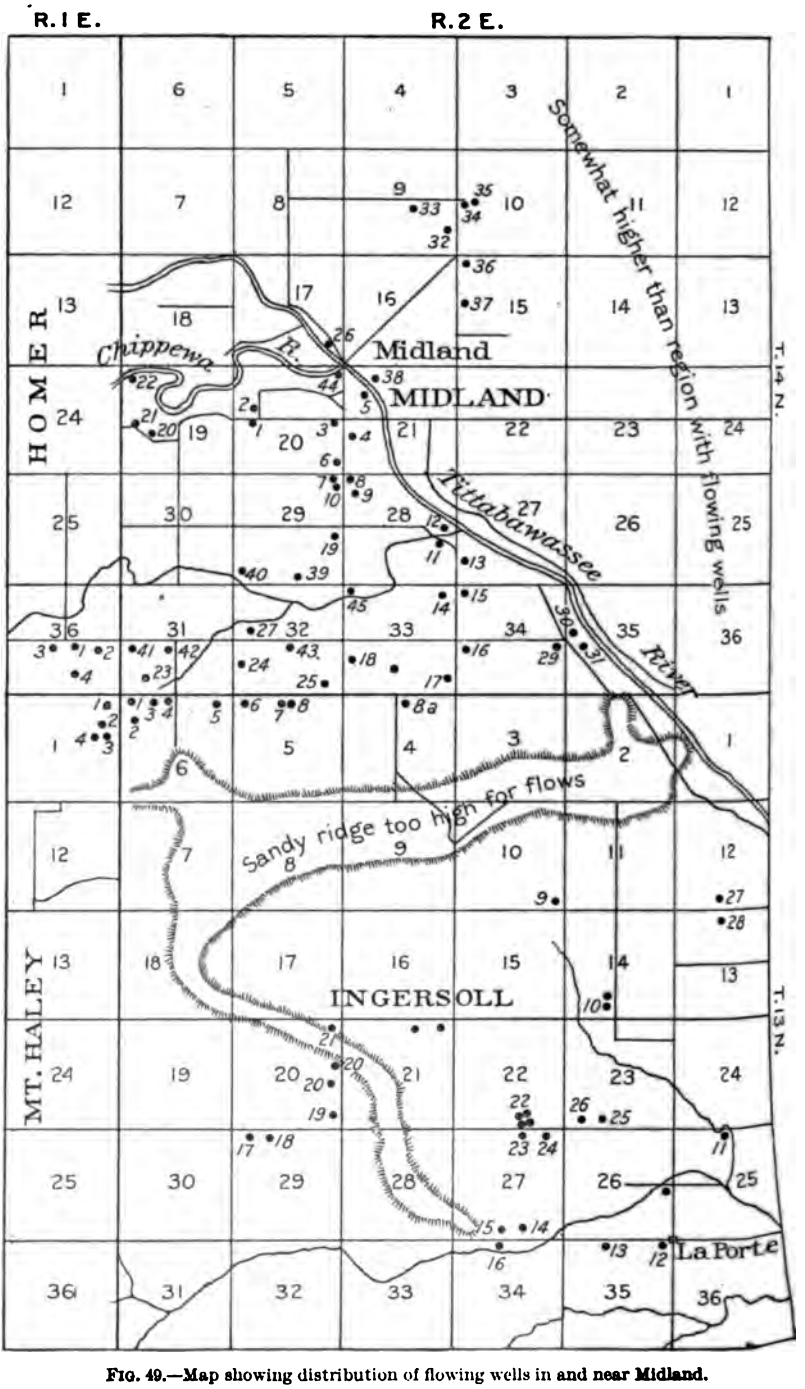


FIG. 49.—Map showing distribution of flowing wells in and near Midland.

following partial analysis shows the composition of the water of ſagnetic Mineral Spring" or well at Midland, owned by W. L. s. The high iron constituent is a conspicuous feature, but e due to the rust of the pipe. Water is from the rock. The ere furnished by M. O. Leighton, of the United States Geolog- ırvey.

Partial analysis of well water at Midland.

	Parts per million.
.....	214
·).....	6
(Cl).....	802
lioxide (CO_2).....	63.76
trioxide (SO_3).....	+522
y.....	293

ewis, analyst. Depth, 375 feet.

VICINITY OF MIDLAND.

area over which flows are found beyond the limits of the town ls southward to the township line and into the southeast corner mer Township, the northeastern part of Mount Haley Town- ınd the northern part of Ingersoll Township. The entire area, v developed, is about 14 square miles.

flowing wells to the south of the river valley are generally shallower, have less head, and flow with much less energy r more than 1 gallon a minute) and it is probable that they are d from entirely different strata. In these wells the water was line, was frequently hard, and contained iron.

ıy of the wells in this and in the Ingersoll Township area were ably affected by the local drought which prevailed at the time writer's visit, and were commonly reported to be flowing much ıan usual or to have ceased altogether since the drought had . North of Midland is a small extension of the area on secs. and 15, in which all but one of the drift wells, which was in a ı valley, had ceased to flow.

s probable that in almost any part of the southwestern portion dland Township, in the lower places, flowing wells can be ıed by going deep enough. The rock surface is, however, lar, and may rise in places in such a way as to interfere with ntinuity of the water-bearing strata above, but so far as learned ck was not usually struck at much less than 200 feet from the e south from Midland. On the top of the higher sand ridges vel is usually above the head of the flows. Wells would best be ı in depressions if flows are desired. Good water, though often hat brackish, may be obtained from the rock, and there is nough to bring it nearly or quite to the surface.

ıe springs were reported along the river southeast of Midland ıg out from under the sand at its junction with the underly-

ing clay. In this case the catchment area is undoubtedly the sand ridge, and such springs should be rather common in the sandy region north and west of Midland wherever a stream cuts through to the clay.

Mr. J. P. Sugnet kindly furnished the following record of his deep well on sec. 10, Midland Township:

Record of Sugnet well, Midland Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface clay	50	50
Hardpan	20	70
Clay	30	100
Sand and gravel	19	119
Red clay	19	138
Sand	3	141
Clay	114	155
Sand rock.		

It was reported also that in the neighborhood of Midland the surface clays and sands were only 10 to 12 feet deep, followed by a bed of sand, often full of water, below which was a hard dark-colored clay or hardpan with small bowlders in it, which was very hard to work. The top clay, often a relatively thin surface deposit, was as hard as the lower bed, and dark colored.

SUMMARY.

The following table gives well data in Midland Township:

Wells in Midland Township (T. 14 N., R. 2 E.)

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
				Ins.	*Feet.*	*Feet*	*Feet.*	*Galls.*	°*F.*		*Feet.*	
1	20	E. Shoupe *a*	1904	2	119½	600	+20 ?	1	49.5	Soft		Gravel.
2	20	W. Vance *b*	1893	2	120	600		.12	53.8	do		Do.
3	20	T. Dunn *c*		2	208	595	+20+	10 +		do		Do.
4	21	W. M. Lee *d*		2	98	598	+3	1	49.2	do		Do.
5	21	Burt Farm		2	206	590	+3.5	20 +		Soft; salt.		Do.
6	20	S. E. Taft	1890	2	98	595	+4	4.5	50	Soft		Do.
7	29	Chas. Hovey *e*		2	85 95	600	+3	4 6		do		Do.
8	28	C. Cromley *f*	1889	2	95	600	+20 +	15	49.3	Fresh; soft.		Do.
9	28	do	1889	2	125	598	+4	.25		do		Do.
10	29	E. F. Abbott *g*		2	95	600	+4	.75	49.2	do		Do.
11	28	F. Clisdale *h*	1889	2	113	600	+3.5	4	49.5	do		Do.

a 75 feet of tough clay, stony below that. Cost, $60.
b Flow cut off at 1½ feet.
c Formerly good flow; water has some salt.
d Piped into house.
e Three wells in small ice pond.
f Piped to house and barn and fish pond. Used for ice pond in winter. Would flow more, but cut down to prevent waste.
g Head about 15 feet when first put down; cased 15 feet; cost, $35.
h Piped to milk house for refrigerating, and to barn.

Wells in Midland Township (T. 14 N., R. 2 E.)—Continued.

Section.	Owner.	When made.	Diameter.	Depth.	Elevation	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
			Ins.	*Feet.*	*Feet.*	*Feet*	*Galls.*	*° F.*		*Feet.*	
8	W. J. DeHarte		2	94	595	+4	3.5	49.5	Fresh; soft.		Gravel.
7	F. Bennett [a]		2	127	600	+4	1.5	50.4	do		Dp.
3			2		610	+2	.5	51	do		Do.
4	H. E. Ackermann		2		610	+3.5	1.5	49.8	do		Do.
4	Chas. Cone [b]		2	55±	615	+4	.12	51	do		Do.
3	W. M. Stoats		2	45	620	+2	.06	51.5	do		Do.
3	J. Stranahan		2	64	615	+ .5	.12	51.5	do		Do.
9	B. Pessley		2			+3	.25	52	Soft; brackish.		Do.
9	J. Tolman [c]		2	80+	615	+0	.12		do		Do.
9	A. Burgoon [d]	1904	2	68	615	−4	.12		do		Do.
9	C. M. Sinclair [e]	1903	2	109	620	+2	.5	49.8	do		Do.
1	S. H. Smith [f]		2	90 ?	630±	+1.5	.5				
2	R. C. Stokes		2	32	630	+1.5	.5	50	Medium; hard.		
2	T. J. Burgess [g]		2	11		+1	.25		Soft		Sand.
7	Reardon Bros [h]		2	192	610	+1.5			Soft; brackish.		Do.
2	S. Richardson [i]		2	45		+2.5			do		Do.
1	H. Gifford [j]		2			+0	.25		Hard		
4	E. McArdle [k]	1900	2	106	590	+ .5	.12	51	Soft; brackish.		
5	County Farm		2	100±	590	+ .5	.25	50	do	200+	
5	do. [l]		2	200±	590	+1	1		Salt	200+	
9	S. Leonard [m]		2	100±	600	−7			do		Do.
9	J. Malony [n]	1903	2	79	608	+1	.12		Soft		Do.
0	J. P. Sugnet [o]	1898	2	116	605	+1	.25		Salt	155	Do.
0	J. P. Sugnet [p]	1902	2	288	605	+1	.25	50.5	do	155	Sandstone.
5	C. Overton [q]		2	50		− .5			Hard		Gravel.
5	A. Hinkley [r]		2	60		+0			do		Do.
1	Dow Chemical Co.	1900	2	127	600	+2	2	50	Salt	260+	
9	C. Martindale		2	124		+2					Do.
9	J. Reardon		2	144							Do.
1	Wm. Haley		2	32		+1					Do.
1	T. Pear		2	100		+1					Do.
2	R. C. Stokes		2	210							
0	Midland waterworks.	1884	2	190	592	+4	.5	50	Soft; salt	260+	
3	A. D. Salisbury		2	106		+2	2	49.5	Soft		

ed only 16 feet.
d for cooling milk.
off at 3 feet below surface to flow into reservoir and is pumped. Flows to stock trough below

ws in cellar and at trough at side of bank. Cost, $27.
d in milk house for cooling.
pped flowing from barrel into which pipe runs.
w smaller than usual; leaks around casing.
t drops from pipe; decreased from 1 gallon a minute.
rn well flows more in wet season; house well, 16 feet, has large supply good water; head, −3 feet.
ws into basin; water rises about to surface; two wells of same kind at barn.
ws more than formerly.
o salt to use.
mped with chain pump from tile basin; used to flow small stream 1 foot above surface.
stream valley in pasture 10 feet below general surface.
ing sand pumped when visited.
w from 195 feet, smaller one at 116 feet, also at 157 feet.
36 stopped within an hour of the time No. 37 was completed; then had head of 2+ feet and flow
llon a minute; pumped now.
ws into reservoir and is pumped.

INGERSOLL DISTRICT.

There is a distinct area of flowing wells in the southern half of Ingersoll Township, extending into Mount Haley and Homer townships and separated from the southern part of the Midland area by a broad, low-ridged tract of sand which runs nearly west across the township from the river to the western town line and then southward and eastward. The flowing wells in the north part of the township belong in the Midland area (fig. 49).

The surface of this district is very flat, aside from sand ridges, and the soil, except on the ridges, is a heavy clay loam, which from its fineness of texture is relatively impermeable to water.

In the sandy areas water is easily obtained by digging or boring from 10 to 20 feet through the sand to the underlying clay. Such wells usually furnish a good supply of water, the sand acting as the catchment area and absorbing about all the water that falls on it. In this type of wells, however, care should be taken to locate the well at a considerable distance from all sources of contamination, such as barnyards, outhouses, etc.

In the early settlement of the township dug wells were general in the clay lands as well as on the sand, but as the timber disappeared and the land was cleared, the ground-water level became lower and the wells were deepened either by digging or, more commonly, by boring in the bottom of the basin of the old well.

It was found that over a considerable part of the township the water which was struck by boring at a relatively short distance down would rise to the surface or flow over it. As indicated above, these wells are usually relatively shallow, with a few exceptions in the eastern part of the township, where they are reported to be from 100 to 200 feet deep, their depth usually exceeding 50 feet. The head is slight, not often more than a foot or two, and frequently the water does not rise quite to the surface. Many of the wells of the area flow, not from a casing, but from the top of the dug basin, through an open ditch to the roadside. This is a probable source of contamination to the basin, since in this open ditch filth of all sorts may accumulate and, despite the fact that there is a constant current flowing from the well, will eventually find its way to the basin and pollute it. A glance at the condition of some of these open ditches would convince even a casual observer that they were foul in the extreme, and it is easy to see how a heavy rainfall might wash much of the filth into the basin. If this type of well is to be used and the overflow is to be allowed to run off near the surface, a tile drain should be carefully laid to replace the open ditch.

In every flat country where it is difficult to dispose of waste water it would be a most excellent plan to construct a basin of concrete which should be water-tight and built high enough above the groun

prevent overflow. The same purpose could be attained by the e or large-sized sewer tile, or by piping the well above the surface d into a trough, which should be high enough to prevent overflow. this way a surplus of water would always be on hand, and yet ere would be no waste.

The water from these wells is of medium hardness in most cases. sh, and of good quality.

The water is said to come from a thick bed of sand, lying under a atively shallow clay deposit. In one well on sec. 4, the record s clay 60 feet, sand 116 feet. In another well farther south it s reported that the record was clay 35 feet, sand 72 feet. Neither these wells flowed, and they were deepened in the hopes of secur- g flowing water.

It is frequently reported that there has been a loss of head in these lls. Several have ceased flowing entirely, and have been cut off d fitted with pumps. The cause of this loss is not apparent, unless be the dry weather. It did not seem to be generally true that the pply had been drawn on too heavily by overdevelopment, for in case were the wells closely crowded together, nor were there any ry large flows found. The apparent cause, therefore, is the general wering of the ground-water level by excessive drought, which has turn reduced the pressure that caused the head.

An extension seems possible to the west when the country is fully ttled, and it also seems likely that a greater number of flows might had in the district at present developed if care is taken in putting wn the wells and in properly casing them.

The sketch map of southeastern Midland County (fig. 49) shows e relation of this area to the Midland area, and the approximate tent of the area, while the facts relating to the wells are to be found the table on the next page.

Wells in Ingersoll district.

INGERSOLL TOWNSHIP (T. 13 N., R. 2 E.).

No. on fig. 40.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	6	Ellen Patrey		2	50±	630	+1	0.25	51	Soft	Gravel or sand.
2	6	....do		2	50	630	+1	.12		....do	Do.
3	6	Thos. Bailey [a]	1890	2	33	625	+2	.06		....do	Sand.
4	6	Thos. Lindsay	1890	2	108	625	+2	.12		Medium	Do.
5	6	Jos. Yott [b]		2	625	625	+2	.25	52	Hardiron	Gravel.
6	5	Wm. Downs		2	112	625	+2	.25	50	Soft	Do.
7	5	F. Yott [c]		2	97		+2	.25	50	....do	Sand.
8	5	....do.[c]		2	110		+2	.5	49.6	....do	Do.
8a	4	G. Warner		2	36		+1	.25			
9	10	W. Saas [d]	1895	2	180+		+0	4-8		Salt	
10	14	G. O. Walker [e]	1896	2	167		+5.	.33		Soft	Gravel.
11	25	Geo. Cook [f]		2	160		−3				
12	35	D. L. Chamberlin [g]		2	30		+0	5		Soft	Sand.
13	35	W. Gould	1894	2	37		+1.5	.25		....do	
14	27	W. Baker [h]	1894	2	26		+1.5	.12		Hard	Do.
15	27	....do	1888	2	30±		+0	.25		....do	Do.
16	34	....do.[i]		2?	25±		+0	1		....do	
17	29	G. Stuart [j]	1903	2	22		+2	2		....do	Do.
18	29	G. McDonald	1902	2	58		+1.5	1		....do	
19	20	F. Compton [k]	1903	2	38		0			Medium hard.	
20	20	S. Locke [l]	1895	2	17		+2.5				
21	20	Cheese factory [m]	1901	2	50		−4	1		Medium hard.	
22	22	B. B. Bartlett [n]	1884	2	90+		+1	.5			
23	27	....do.[o]	1884	2	70		+1.25				
24	27	G. Bartlett		2	60		+2.5	.5	50	Hard	Sand.
25	23	Mary Lee [p]	1898	2	20±		+0	5-10		Iron	Do.
26	23			2	20		+0	1-2		Hard	
27	12	L. O. Schoffler		2	36		0				
28	13	....do		2	60		0			Iron	

HOMER TOWNSHIP (T. 14 N., R. 1 E.).

1	36	A. McLaughlin [q]	1896	2	36	630	+1.5	0.55	49	Soft; iron	
2	36	C. Mudd [r]	1895	2	35	630	+1.5		51	....do	Gravel.
3	36	....do.[s]			40	630	−5			....do	Do.
4	36	W. Blowers [t]	1895	2	35	635	−1			....do	Do.

MOUNT HALEY TOWNSHIP (T. 13 N., R. 1 E.).

1	1	H. A. Crane [u]		2	100	635	−2	0.06		Soft	Gravel or sand
2	1	....do		2	55	635	+0	.12	50.2	....do	Do.
3	1	....do.[v]		2	65	635	+ .5			....do	Do.
4	1	....do		2	72	635	+1	.12	54	....do	Do.

[a] Flows more in wet seasons.
[b] Flow has decreased. Dug well here formerly used to flow; head, −1 foot.
[c] Both wells flow less than in the spring.
[d] Flows into old dug basin from which a good stream of water runs into roadside ditch.
[e] Cut off into basin.
[f] Formerly flowed in barnyard on side of bank, but is stopped now.
[g] Dug 9 feet, drilled 21; flows from basin into ditch; pumped.
[h] Flows more in wet seasons.
[i] Partly dug; pumped with chain pump; flows into ditch.
[j] Pumped; lost head during dry weather; water turbid when pumped.
[k] Pumped.
[l] Flow stopped temporarily by sand.
[m] Flows into cemented tank. Factory uses 6 to 8 barrels a day.
[n] Mr. Bartlett has four or more wells of about this depth which formerly flowed; now pumped.
[o] House well, pumped from brick cistern 26½ feet deep.
[p] Bored in bottom of dug well; flows over surface in large stream.
[q] Flows less than formerly.
[r] Water just drops from pipe because of drought.
[s] Does not flow, but water comes near surface.
[t] In a pasture; water rises to within a foot of surface into a barrel.
[u] Flows into barrel near barn; flows better in wet parts of year.
[v] Much affected by drought; runs only about a drop a second.

GREENDALE TOWNSHIP.

'his area is located in the south part of Greendale Township, about lway between Midland and Mount Pleasant, in the valley of a utary of Chippewa River. (Fig. 50.)

The area includes four wells, all about the same depth, located thin a mile of each other. All have small or medium flows preting no peculiarities. It is probable that other flows could be veloped along the stream valley east and west. The owner's postice address is Stearns. The driller, Mr. A. Kinney, resides at easant Valley. The following table sets forth the available facts:

Wells of Greendale Township (T. 14 N., R. 2 W.).

Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Quality.	Water bed.
			Inches.	*Feet.*	*Feet.*	*Galls.*		
28	T. C. Gibbs	1900	2	72	+2±	0.25	Good	Sand.
27	W. Conrad	1900	2	68	+3	.5	Soft	Do.
27	H. Gotham	1900	2	68	+2±	5	....do	Do.
28	G. W. Hitzmann	1900	2	±68	+2	3	....do	Do.

JASPER TOWNSHIP.

This area lies in the southwest corner of Midland County, 5 miles st of Shepherd and 5 miles north of St. Louis, and covers an area about 10 square miles, a location that ings it well within the region formerly vered by a Glacial lake in the Saginaw sin. Because of this history its surface nearly flat and its soils are usually clays or y loams, broken by low, irregular ridges sand.

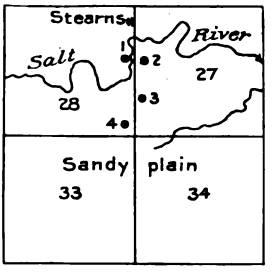


FIG. 50.—Map of Greendale Township flowing-well area, Midland County.

Depending on situation and the kinds of ls, there are two types of wells—shallow g wells and deeper drilled or bored lls. The former are generally in sandy tricts and the latter in the clay and my areas. The sand is usually rather shallow and superposed on the clay. This allows the rain water to run through to the lerlying clay, saturating the bottom layers of the sand, from ch shallow wells may draw an abundant supply of water at a th of 6 to 15 feet. Such wells are usually made by sinking a few gths of sewer tile of sufficiently large diameter to the wet sand. n the clay and loamy sections the dug wells are usually deeper n in the sandy areas, but there are many which were originally ut 15 feet. These obtained their water from thin strata of sand ravel in the clay. Since the settlement and clearing of the coun- these shallow wells have in many cases failed and have been

deepened by boring. Tubular wells are very common in the clay lands, and range from 17 to 200 feet in depth, generally obtaining good supplies of rather hard water from sand or fine gravel interbedded with the clays.

Many of the tubular wells flow above the surface, and the whole southwestern part of the township is apparently underlain by water-bearing strata at depths varying from 15 to more than 200 feet, from which the water rises 6 to 14 feet or more above the surface. Mr. Armstrong Kinney, of Pleasant Valley, stated that one-half mile west of Pleasant Valley flows are obtained at from 16 to 30 feet. At Pleasant Valley post-office the shallow wells do not flow, and flows are only obtained from below 100 feet, but 1 mile east of the post-office there is a flow, said to be from about 200 feet. Farther east the flows are from nearer the surface, forming a distinct flowing-well area. The usual head is only from 1 to 4 feet, but J. M. Fox's well, in sec. 32, was reported to flow 14 feet above the surface when first completed. Mr. Kinney estimated the average height to which the water rises above the surface in the flowing wells of the township as 18 inches or less.

The water usually comes from fine sand, and drillers report it as too fine to be screened out. In confirmation of this some wells are said to become more or less turbid before a storm and to require frequent sand pumping. This turbidity, in part at least, is due to the effects of lessened pressure of the atmosphere at such times, which allows the water to flow from the outlet more rapidly and carry with it the finer particles of sand or gravel from the water bed.

The flows are generally of medium or small size, but sufficient for ordinary farm and domestic purposes. The wells of Messrs. M. Robeson and J. W. Fox, sec. 32, and J. Tuger, sec. 29, are among the largest flows in the area, while a few of those visited are apparently nearly clogged up from the packing in of sand at the bottom of the casing. A few wells were reported as affected by the weather, flowing more freely in the rainy seasons.

The water of the wells of this area is moderately soft and contains less iron than is usually present in waters from the drift.

This township may be considered as having two areas of flows, the deeper wells on the western side belonging to the Coe area, extending from Isabella County, and the shallow ones deriving water from local strata. The latter area is best developed along the east and west county line in secs. 15, 16, 21, and 22, where the wells give small flows with rather slight head at depths from 30 to 70 feet. These wells are affected by droughts, and several of them have ceased to flow.

Flows from shallow strata are obtained in various other parts of the township, notably in the southern sections. In sec. 32 are three

ells arranged in a triangle about 100 feet on a side which are 32, 55, d 76 feet deep, respectively. These are on the farm of Mr. Mark beson, who has another well 43 feet deep which flows a 2-inch pipe l.

It is possible that these areas of flowing wells may be extended to e north and to the east beyond Pine River, as the need for deeper ells in these districts arises. At present, since there is considerable nd in these sections, the wells are mostly shallow. The well at the oolhouse, sec. 27, is reported as being the most eastern flow in the wnship and the most northern in the vicinity of the river. If flows e desired, it should be borne in mind that here, as elsewhere, other ings being equal, the wells put down where the ground surface is west, that is, in depressions, are most likely to flow and give large antities of water. Where the owners' buildings are on elevations, e wells should be at the lowest possible point and the water from em forced to the buildings by a hydraulic ram.

For particulars relating to the flowing wells of this area and a map owing their distribution see pages 93–100, which include also data eviously gathered by Mr. Gregory. In some cases where there is a ight disagreement the record obtained by the writer is supplemented y the data collected by Mr. Gregory, the latter being followed by the itial "G."

GENEVA AND WARREN TOWNSHIPS.[a]

There are a few flowing wells in secs. 16, 17, and 18, Geneva Township, and one in sec. 19, Warren Township, which are so remote from he wells of the Isabella basin that it scarcely seems advisable to nclude them in it. The data given below concerning the depth and lowage of these wells were obtained from a well driller, none of the vells being seen by the writer. Possibly other flowing wells occur arther east in the county, for the surface descends eastward and the nderground water probably takes that course from the higher land n Isabella County. There was insufficient time at the writer's disposal to clear up that district properly.

Wells in Geneva Township, Midland County (T. 15 N., R. 2 W.).

Section.	Part of section.	Owner.	Depth.	Flow per minute.	Remarks.
			Feet.	*Gallons.*	
8	.....	J. E. Curtiss	80	.....	No flow.
16	NE. ¼	M. McDonald	106	.....	Small flow from sandy bed.
16	N. side	D. A. Wilson	106	2.5	
17	W. side	Lyman Childs	115	.....	Through clay; small flow.
17	NE. ¼	Albert Beuhke	90	.....	
17	NE. ¼	Sam Walker	190	.5	
18	NE. ¼	D. McFarlane	80	3.1	
4	.....	Wm. Tripp	29	2.	Cased 16 feet.

[a] By W. M. Gregory.

Wells in Warren Township, Midland County (T. 16 N., R. 2 W.).

Section.	Part of section.	Owner.	Depth.	Flow per minute.	Remarks.
			Feet.	*Gallons.*	
19	SE. ¼	L. A. Bliss	80	0.8	Small flow.
7	NE. ¼	Phil Preston	100		Water scarce.
19	Center	Test well	300		No flow; water scarce.
17	NE. ¼	J. Marihood	79		Do.

WATER SUPPLIES OF SANILAC COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Sanilac County fronts on the southern part of Lake Huron. Along the border is a plain 3 to 5 miles wide, once covered by lake waters, on which several small flowing-well districts have been found. Back of this is the Port Huron moraine, filling the interval of 2 to 6 miles between the lake plain and Black River and forming a catchment area for the flowing wells east of it. Along and west of Black River are extensive swamps, and the western two-thirds of the county is largely level land. The Marlette moraine crosses the southwestern part of the county from Marlette to Melvin. Narrow ridges run from the inner or north border of this moraine northward several miles into the plain. There are also narrow strips of ridged drift, generally gravelly, scattered over the western part of the county. The northwestern part of the county, on each side of Cass River, is morainic and very thickly strewn with bowlders. There are a few small flowing-well districts west of Black River discussed below.

The western part of the county is tributary to Cass River through streams draining westward or northward. The central portion is drained southward through Black River, which enters St. Clair River at Port Huron. The eastern edge of the county drains directly toward Lake Huron. The waters of the Glacial Lake Whittlesey covered much of the swampy land along Black River and discharged through the Ubly outlet in southern Huron County into a lake across whose bed Cass River takes its course from Ubly southwestward.

The southern part of the county and all the shore except the northern third is thickly covered with drift. But in the remainder, or more than half the county, rock is struck at depths usually of 25 to 75 feet, and there are a few rock outcrops along Cass River in the northwestern part and along the lake shore in the northeastern part. The rock in the central, northern, and western parts is Marshall sandstone, and contains abundance of excellent drinking water. The southeastern part is underlain by shale, and this affords but little water and that generally of poor quality. The drift is therefore the main source for

ater in the southeastern part, but the sandstone is largely drawn on in the remainder of the county. East of Black River in parts of e morainic ridge and in parts of the lake plain the drift is also a poor ater bearer. As a result farmers on the lake plain have in some cases en obliged to haul water either from neighboring wells or from Lake uron and have impounded water for stock by placing dams across all streams tributary to Lake Huron.

WATERWORKS.

The following villages have waterworks for fire protection and lawn rinkling, but not for domestic use: Brown City, Croswell, Lexington, and Carsonville. Marlette has a supply for domestic use as well fire protection.

BROWN CITY.

This town, in the southwestern part of the county, has several allow wells, excavated to depths of 6 to 20 feet along the base of a ift ridge. These are drawn upon in case of fire. There is also a llage well 217 feet deep and 3 inches in diameter, made in 1903, hich is strong and is used for street sprinkling. It struck rock at bout 190 feet. The water in it rises to 12 feet below the surface, or 87 feet above tide. Another well at the electric-light plant is about 00 feet deep, penetrating into rock a few feet. In it also water tands 12 feet below the surface, but it is not a strong well. The vater is used in boilers. Other deep wells in the village similar to hose just mentioned are at the Harrington Hotel, a creamery, and a anning factory. The Harrington Hotel, however, now obtains a supply at 140 feet from gravel. Wells in the northwest or main residence part of town get plenty of water in gravel below till at 50 to 70 feet.

MARLETTE.

Marlette, in the southwestern part of the county, obtains a waterworks supply from wells drilled into rock on low ground in the northern part of town. The water stands nearly level with the surface and s pumped direct to the mains with an ordinary pressure of 40 pounds nd a fire pressure of 80 pounds The plant was installed in 1896 at a ost of $15,000.

CROSWELL AND LEXINGTON.

The village of Croswell, in the eastern part of the county, has a supply from Black River for fire protection and sprinkling. Water is pumped to an elevated wooden tank. The plant has been in operation since 1895. The domestic supply is from private wells, usually about 30, but in some cases 100, feet deep.

Lexington is the only village on the lake shore in this county that has water stored for fire protection. The wells used for this purpose flow into two underground wooden tanks 8 by 16 by 10 feet deep with which the hose and fire engine are connected. The wells are 21 to 23 feet deep. The public school has a flowing well 42 feet deep. (For flowing wells of the district see pp. 249–251.)

In the following table partial analyses are given of water from several sources at Croswell and Lexington. The Black River supply is used only for sprinkling and fire purposes and is as good as the water from the shallow wells. A safer supply is from deep wells, such as that at the Croswell Hotel. The deeper well at Lexington is in the rock. The data were furnished by M. O. Leighton, of the United States Geological Survey:

Partial analyses of waters near Croswell and Lexington.

[Parts per million.]

	1.	2.	3.	4.
Color	46	24	149	71
Iron (Fe)	1	1.25	3	2
Chlorine (Cl)	36.9	29.3	49	11.5
Carbon dioxide (CO_2)	90.53	58.88	105.70	94.32
Sulphur trioxide (SO_3)	36	5	15	5
Hardness (as $CaCO_3$)	139+	139+	139+	139+

S. J. Lewis, analyst. 1. Black River, Croswell. 2. Croswell Hotel, Croswell; depth, 101 feet. 3. R. Pabst, Lexington; depth, 910 feet. 4. School district No. 6, Lexington; depth, 42 feet.

CARSONVILLE.

There is a waterworks plant connected with a mill in Carsonville, but it is apparently not for general use. The water is pumped to an elevated tank.

SANILAC CENTER.

In 1904 plans were developed at Sanilac Center to install waterworks and draw the supply from drilled wells, which afford a large and excellent supply from 70 feet or less.

MISCELLANEOUS VILLAGE SUPPLIES.

The tabulated data on village supplies in 1904 were obtained largely by correspondence with residents. The data collected by C. H. Gordon some years earlier for the Michigan Geological Survey pertain both to village and rural supplies, and may be found in vol. 7 of the report of that survey published in 1899.

Village supplies in Sanilac County.

wn.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
s.....	.....	763	Open and driven wells...	.....	15	30	20	25	.....	Small.
te.....	.....	740	Driven wells.....	.....	10	30	20	20	.....	None.
.....	.....	800	Open and driven wells...	40	16	104	25	65	−14	Small.
'ity.....	603	811	Bored and driven wells.	190 +213	14	217	60	180 200	−12	Do.
ille.....	400	767	Open and driven wells...	.....	15	65	30	30	−12	None.
.....	.....	760	Open and driven wells and creek.	40	20	152	22	.....	.....	
.....	606	731	Open and driven wells and river.	.....	10	100	20	.....	.....	
ille.....	398	778 830	Open and driven wells...	60	16	80	35	70	− 5 −20	Small.
.....	.....	790	.....do.....	20	20	60	26	26	−20	None.
lle.....	282	610	Open wells, Lake Huron.	.....	10	33	25	25	.....	Small.
rer.....	.....	800	Drilled wells.....	40	20	160	60	60	−20	Do.
f.....	.....	800	Open and drilled wells...	36	8	70	.....	.....	.....	Do.
.....	.....	780	.....do.....	40	8	165	20	75	− 0 −10	None.
on.....	619	620 660	Flowing wells.....	.....	18	72	20	20	+ 7	Strong.
'.....	996	840	Open and drilled wells...	60	20	150	60	100	−10	
.....	.....	826	Bored wells.....	120	12	380	30	30	−30	Small.
.....	408	818	Drilled wells.....	75	20	100	80	100	.....	None.
.....	.....	812	.....do.....	50	13	176	100	100	−36	Do.
nilac.....	314	600	Open and drilled wells...	.....	12	60	40	40	−25	
Center...	578	780	.....do.....	50	10	100	80	80	− 6	Small.
re.....	.....	780	.....do.....	20 100	15	175	15	75	−10	

FLOWING WELLS.

LEXINGTON DISTRICT.

e flowing wells of the Lexington district are restricted to a nar-trip extending from the cemetery at the north end of Union southward through the west part of the village between Union lain streets and about a mile beyond, or into the southwest part . 31, T. 10 N., R. 17 E., as shown in the sketch map (fig. 51). strip is scarcely one-eighth mile in average width. The border-acts appear to have been thoroughly tested, several attempts tain flows at lower levels along Main street having been unsuc-l as well as those on the higher ground along and west of Union . There are springs to the north of this strip of flowing wells also to the south, which may belong to the same pool. The area of the flowing-well strip, not including the springs, is less half a square mile, while the number of successful flows in opera-n October, 1904, is not less than 21. They are at an altitude 50 feet above Lake Huron or 630 feet above tide. The wells om a bed of sand beneath a thin sheet of clay apparently till, hose in the village are just east of the Elkton beach. With one tion they are less than 25 feet in depth, while some, as indicated e table below, are but 10 or 12 feet. The schoolhouse well on the

west side of Valen street is 42 feet deep. It reached a deepe than the others, and apparently is at the eastern edge of the di for a boring 88 feet in depth on the opposite or east side of street failed to get a flow. The water is piped to the school gr

The first well was made about twenty years ago by John Bel the north end of the present strip of flows. Others nearly as c the Purkiss well on the north side of Lake street, west of Vale a well owned by Walters & Co., sunk only a few feet from the s house well.

It is the custom for two or more families to join in putting c flowing well and then pipe the water to each residence. In th nearly all the residents east of the flowing-well strip as well a have been supplied, for ther rapid descent in the lake plai the well strip to the lake bluff

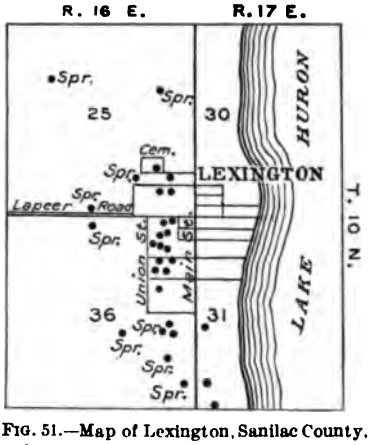


FIG. 51.—Map of Lexington, Sanilac County, showing flowing wells and neighboring springs.

The water is not very ha contains only a moderate amc iron. (See analysis of scho well, p. 248.) It is very prized by the residents beca its quality, and care is taken vent waste, most of the wells faucets or other means for s off the flow when not needed.

The rate of flow where tes made is about 2 gallons a minu 1-inch pipes having half-inch i In most cases the rate is diff determine because of the distr of water through two or more pipes.

The temperature tests were of more value in showing the of the soil through which the pipes are conducted than the temperature. Several wells had, on October 11, at 9 to 10 a temperature of 55.5° or about 7° above the usual temperatur flowing wells in that region and 7.2° above that of a large flowi 3 miles south of Lexington, discussed below. It is probable t soil temperature at that time was sufficient to increase the te ture of the wells 7°. The winter and early spring temperature water as it issues from the pipes are likely to be much below t mal water temperature. A series of carefully conducted wat perature observations would, if carried through an entire y likely to yield important data on variations in soil temperatu

following data concerning the wells, and the plat of the village, ırnished by the president of the village, J. F. Meyer:

Flowing wells at Lexington.

wner.	Location.	Depth.
		Feet.
Association..	North end of Union street	18
.....	About 20 rods southeast of cemetery	19
ksbury.....	South side of Simmons street	19
.....	South side of Lapeer road	20
illac.....	South of Lapeer road	21
se.....	West side of Valen street	42
Co.....	10 feet from schoolhouse well	21
.....	North side of Lake street	21
iller.....	South side of Lake street	21
ll.....	20 rods west of Miller well	21
.....	In sag between Lake and Hubbard streets	17
ll.....	North of Hubbard street	23
r.....	15 feet west of village well	23
ard.....	200 feet east of Hicks well	20
shank.....	South of Lester street	19
s.....	do	19
nett.....	West of Main street	18
n.....	80 feet southwest of Janett well	18
.....	Northwest corner of SW. ¼ sec. 31, T. 10 N., R. 17 E.	10
.....	West side of SW. ¼ SW. ¼ sec. 31	12
.....	South side of SW. ¼ SW. ¼ sec. 31	12

Important springs near Lexington.

wner.	Location.
rk.....	SE. ¼ NE. ¼ sec. 25, T. 10 N., R. 16 E. (Boils up with great strength.)
ison.....	SW. ¼ SE. ¼ sec. 25.
nd.....	SE. ¼ SW. ¼ sec. 25.
ɔley.....	Near center of NW. ¼ sec. 25.
and.....	Northeast corner of NW. ¼ sec. 36.
.....	East part of NE. ¼ SE. ¼ sec. 36.
l.....	South part of NE. ¼ SE. ¼ sec. 36.
enney.....	East part of SE. ¼ SE. ¼ sec. 36.
tt.....	NE. ¼ SE. ¼ sec. 36.

R. Pabst, of Lexington, sunk a well 900 feet deep in the valley Creek, 3½ miles south of Lexington and about one-fourth mile he shore of Lake Huron, at a level 10 to 15 feet above the lake or 595 feet above tide. At a depth of 132 feet, near the base of the , strong flow of water was obtained, which runs 15 gallons a min- d will yield by pumping ten times that amount. The water is ,nd of excellent quality, with a moderate amount of iron. (See is, p. 248.) Another vein with sulphur water was struck at et, which rises to the surface but does not flow with such th as that from the glacial deposits. The temperature of the ıed waters as they escape from the well mouth was 48.3° .F. ɜr 11, 1904. The same water was found by Doctor Lane some ɜarlier to have a temperature of 48°, but his observations were .er weather. Whether this difference is attributable to a change t amount in temperature of the water or is merely referable to nces in the graduation of the thermometers is not known. The is going to waste at present, but may be developed if that part lake shore becomes a summer resort, for it stands in a very tive *piece of forest suitable* for a park.

BUEL FIELD.

The main group of wells in Buel Township is on the western side of a sharply ridged belt of gravelly drift a short distance southwest of the center of the township. There are other flows at the south end of the ridge on the Fremont side of the line of Buel and Fremont townships and a very strong spring issuing from the base of the ridge between these groups of wells in the west part of sec. 33, Buel Township. It seems proper to throw all of them into a single field with the gravel ridge as the catchment area. There are two other flowing wells in Buel Township about 3 miles east of this ridge, which, though fed perhaps by the same catchment area, are on its opposite side and perhaps in a different pool, unless the flowing-well field completely surrounds the ridged belt.

The group of wells west of the ridge are at an altitude about 760 feet above tide, those at its south end about 770 feet, and those on the plain to the east of the ridge about 750 feet, while the ridge has an altitude of 800 to 810 feet along its crest. The water has barely sufficient head to flow, and probably would not rise more than 5 feet above the surface in any well. In some it rises barely level with the surface and escapes along ditches connecting with the wells. In some wells pumps are attached.

The oldest wells were made in 1871, and several have been made twenty years. The head seems to have decreased slightly, and this has led to the use of pumps, for it is considered more convenient to pump the water than to maintain a good drinking place for stock at a level a foot or two below the ground surface.

The wells on the west side and south end of the ridge are very shallow, ranging from 10 to 30 feet in depth. Those on the plain east are 40 to 50 feet. They all pass through clay before striking the water, which is obtained in sand or fine gravel.

The temperature showed a range from 49° to 53° in the different wells, all being taken in a single forenoon on October 8, 1904. The temperature of the large spring referred to above was 52° on that date. The varying effect of the warm surface layers of the earth on the waters rising through them seems a sufficient reason for the variations displayed.

Only one well, that of C. J. Nelson, was in good condition for testing the rate of flow, and this yields but a gallon in four minutes. The spring flows a stream several inches in diameter, producing a small creek as it runs across the plain west of the ridge, and yields much more water than the combined flow of all the wells.

The water is hard and has sufficient iron to produce the characteristic orange-colored scum upon objects over which it passes.

Wells in the Buel field (T. 10 N., R. 15 E.).

rt of tion.	Owner.	When made.	Depth.	Head.	Temperature.	Remarks.
			Feet.	*Feet.*	°*F.*	
¼...	Aaron French.....	1871	15	−1.5	.....	Well stopped flowing in 1896.
¼..	.....do.....	1874	17	−1	52	Well stopped flowing in 1901.
¼..	Aaron French (barn near house).	1894	25	(?)	50.5	Pump attached.
side.	Aaron French (in pasture).	1893	30	0	49	Water rises to surface and forms pool.
side..	W. Francis.....	1889	21	+2	49	Dug 12; bored 9 feet through clayey till to sand.
ide..	W. J. Stratton.....	1895	20	+1	50.2	Pump attached.
side..	Thos. Coggin, Buel...	1884	50	+1	(?)	Well plugged.
ide..	Geo. Carey, Buel.....	1880?	40	0	(?)	Head was lowered by flow of Coggin well.
¼...	A. Wheatley, Buel...	.....	.....	.....	.....	Not visited.
ide..	W. H. Carey, Buel...	.....	40	−10	.....	On ground 770 feet above tide. Head higher than in wells to the east.
side..	C. J. Nelson, Fremont.	1894	13	+3	50.5	Crock well; flow 1 quart a minute.
side..	I. Johnson, Fremont.	(?)	12	(?)	53	Pump attached.

PECK DISTRICT.

village of Peck stands on the eastern slope of a morainic spur tends northward from the Marlette moraine in Speaker Town- . 9 N., R. 14 E.) into the southern part of Elk Township N., R. 14 E.). The water in the wells on the flanks of this ic spur, both east and west, rises nearly to the surface in a strip ing from the base of the spur in secs. 9, 10, and 11, Speaker ip, northward about 4 miles; seven flows have been obtained ground in the eastern part of the village of Peck, along the line . 27 and 34, Elk Township. The first was obtained twenty go by Barney McGrory; it was dug 18 feet and bored 20 feet , where a strong gushing flow was obtained that filled the dug d flooded the street and dooryard. The dug portion was filled obblestones and bowlders to prevent caving, but the water es to rise through these stones and flow out into a gutter in the The other wells have been made within a very few years. In ses they have been banked up and pumps attached to prevent the pump spout being above the height reached by the water, voiding a muddy place around the wells. The head is apparut 1 to 3 feet, and in one or two cases is barely level with the , so it is easy to prevent a flow. In all the wells the water is in iron and hard, and is not popular for domestic use. The ature of the water is 49° F., if pumped sufficiently to bring it n below the effect of atmospheric heating. The observations ade October 3, 1904, on which date some of the wells showed as the result of atmospheric heating of the pipes near the surthe ground. The rate of flow could not readily be determined, escape is not through pipes, but from a tile into a ditch a little the surface of the ground.

Wells at Peck.

Section.	Part of section.	Owner.	When made.	Depth.	Diameter.	Head.	Temperature.	Mode of escape.
				Feet.	*Inches.*	*Feet.*	*° F.*	
27	S. side	Mrs. Barney McGrory	1884	38	.....	+2	49	By pump and by [illegible]
27	S. side	Mrs. Sunfield	1898	30	2	+2	(?)	
27	SE. ¼	John Welch	.....	18	.....	+2	.....	Not visited.
34	N. side	Calvin Chrystler	.....	.....	.....	+1	49	Pump.
34	N. side	Mrs. Caroline Allen	.....	.....	.....	.....	.....	
34	N. side	Lemington Hall	1904	29	38	0	54	Do.
34	N. side	M. W. Henry	.....	.....	.....	+1	.....	

VALLEY CENTER AREA.

Two flowing wells have been obtained near Valley Center (T. 9 N., R. 13 E.), at the border of a plain that lies on the northwestern side of a moraine passing just south of the village. They are both shallow, one made by Andrew Cook in the SW. ¼ sec. 24, being 18 feet, and the other made by James Campbell in the east part of sec. 22 about 25 feet in depth. The latter well was dug 18 feet and then bored about 7 feet to the vein of water from which the flow was obtained. The former was dug to the water vein. The wells were not flowing at the time of the writer's visit in October, 1904. No definite information could be obtained as to their head in wet compared with dry seasons, though they appear to have a lower head in the dry seasons of the year. It is the opinion of residents that the draining of marshes near the wells has lowered the head sufficiently to stop the flow.

A well 876 feet deep one-fourth mile south of Valley Center in the west part of sec. 27, of which the record was published in the annual report of the State geologist for 1901, has water rising to 8 feet below the surface or 797 feet above tide. The supply apparently comes from near the base of the glacial deposits at a depth of 117 to 149 feet. This well is on ground a few feet higher than the two flowing wells, so may have fully as great head.

The shallow wells probably derive their supply and their head from the neighboring moraine southeast of them. The catchment area for the water supply in the deep well is perhaps in the same moraine, since the record shows the upper 95 feet of the drift to be fine sand, saturated with water, and separated from the lower water bed by only 22 feet of clay. Conditions seem favorable for a rise of water nearly to the surface all along the northwest border of this moraine, for in other wells than those mentioned the rise is within 15 feet of the surface. Yet it may not be possible to obtain flowing wells, since those already obtained seem to have suffered a permanent loss in head that has caused them to cease flowing.

PORT SANILAC FIELDS.

n Sanilac Township, on the shore of Lake Huron, southwest of t Sanilac (T. 11 N., R. 16 E), flowing wells have been obtained in distinct pools. One in the southern part of the township embraces roup of five wells, the other in sec. 10 has as yet but a single well. ey are all on the old lake plain, less than a mile east of the shore of ke Warren, and about 2 miles from Lake Huron, at an altitude 75 100 feet above the level of Lake Huron. The catchment area is parently in each case on the inner or eastern slope of the Port uron moraine. The sand and gravel ridges formed by Lake Warren e on this slope, and probably supply some of the water struck in ells farther east, though, as indicated below, much of the water thus sorbed comes out in springs along the eastern or lakeward base of e shore deposits. There is a rapid descent from the crest of the moine past the flowing wells, the crest being 125 to 150 feet above the vel of the wells and only 2 to 3 miles distant.

The topographic conditions found in connection with the flowing ells are continued along all of this slope of the Port Huron moraine, t the stratigraphic conditions seem to be favorable for flowing ells in only a few restricted areas where water-bearing beds are prest between sheets of clayey drift. There are intervening places ere wells do not encounter such beds, and what little water is tained shows much less pressure than in the flowing wells. No edictions can be made as to the extension of the flowing-well areas cause of this restricted distribution of water beds.

The flowing well in sec. 10 is at the residence of Joseph Pohizehl, on e west side of the northwest quarter of the section, at an altitude out 675 feet. It was made in 1895, and flows a very weak stream, the rate of a gallon in six minutes from a pipe 2½ feet above the surce. The depth is 48 feet, and it enters a sandy gravel below blue l at 44 feet. Neighboring wells toward the south, on ground of nilar altitude, have been sunk to depths of 80 feet or more without taining a flow, the water in some cases remaining fully 30 feet below e surface. A well in the NW. ¼ sec. 14 on ground 40 feet lower has depth of 59 feet and only 15 feet of water.

The group of wells in the south part of the township are very shalw, the deepest being only 30 feet. They are at an altitude about 660 t above tide. The Suerwier wells are on the lake plain, but the ys and Cronkheit wells are in the valley of a small stream trenched to 15 feet into the lake plain. The escape pipes in each are 1½ hes.

Wells in the southern part of Sanilac Township (T. 11 N., R. 16 E.).

Section.	Part of section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Flow per minute.	Temperature.	Quality.
				Feet.	*In.*	*Feet.*		°F.	
34	Center..	Wm. Suerwier (at house).	1894	660	4	28	1 qt.....	49.5	Chalybeate.
34	Center..	Wm. Suerwier (at barn).	1888	660	4	30	1 pt.....	49.5	Do.
27	S. side..	C. Suerwier (at barn)[a]...	1886	665	18	28	Pumped..	49.5	Do.
34	SW. ¼...	David Roys[b].....	1904	660	4	20±	1 gal.....	53	Do.
34	SW. ¼...	Chas. Cronkheit.....	1903	660	3	16	3 gals.....	49.5	Do.

[a] Original head 6 feet.
[b] Probably warmed by exposure of pipe in sunlight; date of observation on wells, October 12, 1904, warm, sunny forenoon.

SANILAC CENTER FIELD.

A single flowing well was obtained in September, 1904, about a mile east of Sanilac Center, on the farm of James McCaren, in sec. 32, T. 12, R. 14 E. It is reported by the owner to obtain the flow from shale rock at depth of 78 to 83 feet, rock being struck at 40 feet. The well is 4 inches in diameter, and flowed a 1-inch stream that rose when struck, to 1½ feet above the surface, but within two months lowered 6 inches. The water is soft, with a slight taste of salt. This well is near the western edge of a swamp that stands only a few feet below the drier land to the west. It seems probable that other flows may be found in this swamp, or at least that water will rise nearly to the level of the well mouth.

In the village of Sanilac Center, in wells of a depth similar to the McCaren well, the water stands 6 to 20 feet below the surface in accordance with the altitude, those on the lowest ground having water nearest the surface; probably in all it rises to very nearly the same altitude as in the McCaren flowing well. The water is soft, and has very little taste of salt.

SNOOVER FIELD.

South of Snoover, at the edges of the swamp which is traversed b the south fork of Cass River, are a few flowing wells from the roc The strongest is in sec. 25, LaMotte Township, in the pasture of T. Miller, and has a depth of 280 feet. It flows the full capacity of escape pipe one-half inch in diameter at a level 3 feet above t surface. The water is not chalybeate and is apparently soft.

Samuel Moore's well, in the central part of sec. 32, Moore Tow ship, has a pump attached, for it barely rises to the surface. T temperature (49.5°) was obtained by pumping.

Albert Jones well, in the east part of sec. 30, Moore Township, w made in 1904 and flows 1½ gallons a minute. This water is rat soft, with little or no iron, and flows 1½ gallons a minute.

A well across the street from the Jones well, on J. R. Dorman fa in sec. 29, once flowed, though on ground several feet higher. has stopped now, and as the head became less before the Jones w was made, that is not the entire cause for loss of head.

Wells in Snoover field.

Township N.	Range E.	Section.	Part of section.	Owner.	When made.	Depth.	Diameter.	Temperature.	Remarks.
						Feet.	*Inches.*	°*F.*	
12	12	25	S. side..	T. J. Miller	1903	280	3	49.3	Rock at 36 feet.
12	13	32	Center..	Samuel Moore .	(?)	100	3	49.5	
12	13	30	E. side..	Albert Jones....	1904	148	3	49.0	Rock at 40 feet.
12	13	29	W. side.	J. R. Dorman...	(?)	(?)	(?)	(?)	

ARGYLE TOWNSHIP.

Two flows are reported in Argyle Township, one at Laing post-office, the other on the farm of William Cole, in the southeast part of sec. 14. They are both on low ground along a tributary of South Cass River. The one at Laing post-office was not properly manipulated, and has become clogged, while the one on the Cole farm had so low a head and so slow a rate of flow that a pump is now attached. Each well enters rock a few feet, and the depth of each is not far from 70 feet.

MINDEN CITY FIELD.

A flow reported by Gordon [a] at the farm of E. Seaman, about 1 mile east of Minden City (T. 14 N., R. 14 E.), obtains its supply from the Marshall sandstone at a depth of 73 feet (67 feet to rock).

A neighboring well on the farm of G. Schweighert has a head only 2 feet below the surface. These wells are at an altitude of fully 800 feet and stand near the eastern edge of the sandstone. In the lower country to the east, underlain by shale, no flows are reported, though wells frequently reach depths of 60 to 80 feet, and occasionally 200 feet. The altitude to the west is higher than at the Seaman flowing well, being 850 to 860 feet along the crest of the Port Huron moraine, so no flows are to be expected. The favorable conditions for flows seem to be restricted to a narrow strip along the edge of the Marshall sandstone at the inner border of the Port Huron moraine.

WATER SUPPLIES OF HURON COUNTY.

By A. C. Lane.

GENERAL STATEMENT.

The water and wells of Huron County have been treated quite fully in the writer's Huron County report.[b] This county constitutes the thumb nail of the thumb of Michigan and is bordered, except on the south, by the waters of Lake Huron. The lake is so shallow around much of the county that it can not be highly recommended

[a] Geol. Survey Michigan, vol. 7, pt. 3, 1900, p. 26.
[b] Ibid., pp. 118-201.

as a source for water, though it is used as the town supply of Harbor Beach. Wells in rock are common and are from three distinct horizons within the county. Those on the east shore strike into shale with little or no water, and that likely to be salt; those in the central part of the county into the Marshall sandstone, where a good supply of water, such as that furnishing the Bad Axe waterworks, can be readily obtained; those in the western part of the county for an area of about 10 miles around Pigeon, pass through gypsiferous beds, but may obtain a good water from the Marshall sandstone if that from the overlying beds is cased out. Probably a more permanent water supply can be obtained from the Marshall sandstone throughout the region covered by it than from the drift.

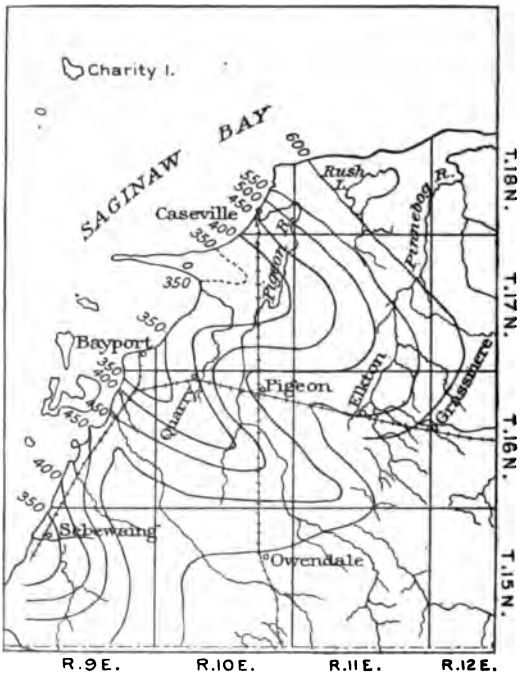


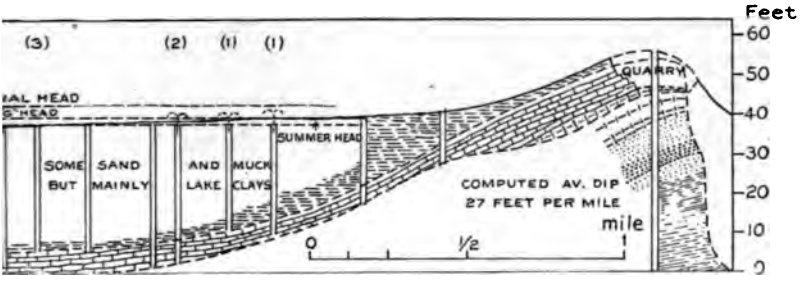
FIG. 52.—Contour map showing the elevation of the top of the Upper Marshall sandstone above sea level.

At the highest outcrops of the Marshall sandstone the water level is about 760 to 780 feet above tide, and probably continues so for about 10 miles north of Ubly. But toward the northwest it drops down to lake level. In general, it may be stated that flowing wells are obtainable on the west-sloping part of the county directly in front of the west-facing terraces and along the stream valleys, or that, at least, the water will rise very close to the surface of the ground. The altitude of the top of the Upper Marshall above sea level is shown in fig. 52, which is taken from the Huron County report. By comparing these contours with the altitude of the present surface the necessary depth of wells can be determined, remembering that the Upper Marshall or Napoleon should be penetrated a certain distance, not over 100 feet, to get the best results.

With the exception of some high ridges in the southern part of the county the surface was once beneath the waters of the lake, and numerous sand ridges running more or less parallel with the present shore indicate old lake beaches. On these sand ridges surface water

be obtained, but it is liable to contamination. Water can often 'ound on this old lake bottom at various depths in the drift, and ›cially just above bed rock. Flowing wells can be found all along shore from Grindstone City to Sebewaing, and sporadically as far)wendale, Elkton, Grassmere, and even to Bad Axe, but draw ely from the underlying rock or its top. Near the Bayport quar- is a small flowing-well area, in Fairhaven and Winsor townships, 'hich the water level fluctuates with that in the Bayport quarries, ndicated in fig. 53. Although prospects for flowing wells are ›rally good on the northwest slope of the county below the 750- contour line, there is not more than 3 or 4 feet of head in any of which I have knowledge.

ı the high ridges in the south part of the county, in Sheridan, ;ham, Paris, and the south part of Verona townships, it is not diffi- to get an ample supply of water without going into the underlying :. There are also some springs in this region. The ridges are n composed of clay till at the surface, but have gravel in the lower s.



3.—Cross section from Bayport quarries southwest, showing relations of the present surface, rock surface, flowing wells, etc.

WATERWORKS.

here are only two systems of village waterworks in this county—at 'bor Beach and Bad Axe.

HARBOR BEACH.

'he Harbor Beach waterworks draw from Lake Huron, a supply e being carried 1,200 feet out into the lake and outside the harbor akwater. It was put in by M. Walker, of Fenton, Mich., at a cost $16,000, and is described in the Huron Times of September 17, '7. It supplies 150,000 gallons a day, or about 100 gallons per ita, though more than half the supply goes to the starch factories.

BAD AXE.

he Bad Axe waterworks are supplied from a number of wells ıt 200 feet deep, from which water is pumped to a standpipe 200 high. The water originally rose 11 feet above the surface; now

it is 15 feet below. It must be remembered that besides the draft on the formation by these and other wells, such as those put down recently in Bad Axe for the sugar factory, the region from which the water is derived has been extensively drained.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table, made up in large part by correspondence with postmasters, presents a summary of conditions at the post-offices of the county:

Village supplies in Huron County.

Village.	Elevation.	Population.	Source.	Depth to rock.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head
	Feet.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Appin	780	(?)	Gravel, sandstone	40	43	102			
Ashmore	650	25	Drilled wells	30-40	30	90	60	50-60	(?)
Bad Axe	758	1,241	Marshall sandstone	30-50	12	400	180	40-180	+2
Bayport	602	250	Drilled wells	5-20	12	60	30	30	-8
Berne	627	150	Drift	40	28	36			
Canboro	680	25	Gravel	30					
Caseville	594	505	Wells and stream	30-40	12	145	22	20	-3
Center Harbor	590	(?)	Rock	5					
Crown	720	(?)	Marshall sandstone	30					
Eagle Bay	590	(?)	do	10	19	25			
Elkton	651	471	Sandstone	30-35	27	200	65	35-65	-20
Grassmere	694	25	Marshall sandstone	40					
Grindstone	590	450	do	10	19	25+			
Gotts	635	30	Drift	30+			28		
Harbor Beach	600	1,400	Lake Huron	30-50					
Hayes	612	25	Michigan series	30	100	218			?
Helena	716	35		90					
Huron	600	60	Drift, sand rock	5	12	70			
Ivanhoe	765	(?)	Gravel	60	30	60			
Johnston	645	75	Lower Marshall	20					
Kilmanagh	630	175	Sandstone	70					
Kinde	701	150	do	50					
Linkville	648	50	Drilled wells	75?	62	185			
North Burns	770		Gravel	(?)					
Owendale	651	75	Drilled wells	38-56	43	170	50-60	60	+2
Parisville	785	125	Sandstone	65					
Pawlowski	775	25	do	60					-10
Pigeon	633	582	Drift and sandstone	40	65	250	175	150	-20
Pinnibog	630	175	Marshall sandstone	30	87	110			-6
Popple	770	45	Gravel	80?	12	35	20	20	
Port Austin	595	507	Lake and drilled wells	10	35	150	75	75	-3
Port Crescent	595	25	Sandstone and drift	20	20	30			+?
Port Hope	597	319	Lake and rock wells	5	10	30	25	25	-6-10
Pointe aux Barques	597	(?)							
Rapson	740	25	Sandstone	50-70					
Redman	710	25		40					
Rescue	720	80	Drilled wells	57	73	126			-4
Ruth	754	180	Open and drilled wells.	70-90	10	100	30		
Sebewaing	593	1,431	Drilled wells	60-80	10	300	60+	100-200	Flow
Sigel	740	60	At edge of Marshall sandstone.	5					
Ubly	785	432	Driven or drilled wells.	70-80	10	100	10-12	90-100	-6
Wadsworth	781	20	do	30-40	20	115	80-115	100-115	-10

SUPPLIES BY TOWNSHIPS.[a]

SEBEWAING TOWNSHIP.

In Sebewaing Township (T. 15 N., R. 9 E.) there is very little water in the drift, for it is composed almost entirely of clay. In some cases, however, the wells obtain water just above the rock, but since coal mining has become extensive such wells are generally deepened into

[a] From detailed records of State survey; see report on Huron County.

ıe rock. These at first flowed, but pumping out the 100 feet of water om mines has stopped the flow. There are also shallow wells on the ınd ridges supplied by surface water. A reference to the rock-con- ɔur map of the county (fig. 52) shows a pre-Glacial valley crossing the ɔwnship southeast of Sebewaing. The extra thickness of drift seems o be due mainly to an addition of sand and gravel at the bottom. 'ossibly some of the sand and gravel is pre-Glacial, but all that has ɔeen inspected in the drillings is plainly Glacial. The three sections 'ollowing illustrate the difference between a well in the pre-Glacial ɣalley and those outside:

Record of Charles Winter well in pre-Glacial valley, sec. 20, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
lay	74	74
ınd and gravel	45	119
arboniferous rock	97	216

Record of Joseph Green well, sec. 11, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
ed or oxidized clay	9	9
lue clay	48	57
ardpan and bowlders	2	59
ınd and gravel with water [a]	1	60

[a] Low in chlorides and strong in sulphates.

Record of well at Saginaw mine, sec. 17, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
ınd	8	8
ay and dry fine sand	12	20
lue clay	28	48
owlders	5	53
ınd rock, etc	212	265

The waters vary in the amount of chlorine, are often strong in sul- hates, and are not infrequently cathartic, especially in rock wells.

In secs. 32 to 34 there is a flowing-well district, in which the tem- eratures are from 50° to 52°. In one case a well in sec. 34 obtained s supply just above the bed rock in quicksand at a depth of 60 feet, ıe altitude was 629 feet and the head 2 feet.

The rock wells of the township may be divided into two groups: Vells from the Carboniferous limestone or from gravel just above it t from 56 to 100 feet, and wells from the Upper Marshall sandstone at epths of 150 to 200 feet. Since the latter pass through dolomitic hales and perhaps gypsum of the Michigan formation, there is need ɔr casing off the sulphated and cathartic waters which these rocks arry.

BROOKFIELD TOWNSHIP.

Brookfield Township (T. 15 N., R. 10 E.) is very flat and except for a triangular tract of about 2 square miles in the southeast corner was originally swamp. The water rises generally above or nearly to the surface. The drift, like that of Sebewaing Township, is mainly clay, with sometimes a little sand or gravel above or below it. From secs. 10 and 14 southwestward the drift is not thick, being usually less than 50 feet, but in sec. 5 it is 115 feet, as shown in the record below, and in sec. 3, 135 feet. The water is variable in quality, chlorine being often perceptible and sulphates varying from nothing to strong.

Record of L. Wisner well, sec. 5, Brookfield Township.

	Thickness.	Total.
	Feet.	*Feet.*
Red clay	13	13
Blue clay	52	65
Hardpan and bowlders	8	73
Sand and gravel	2	75
Mainly sand	40	115
Sand rock with water	25	140

The well of Fritz Matz in sec. 3, 235 feet in depth, apparently penetrated 135 feet of drift, mainly blue clay.

GRANT TOWNSHIP.

In Grant Township (T. 15 N., R. 11 E.) the thickness of the drift varies from only 30 to 35 feet in the northwest corner to a very considerable thickness at the southeast and contains a larger proportion of sand than the townships to the west. Wells are usually obtained at 35 to 60 feet in the southeast part of the township without reaching rock, and the character of the drift is variable. The most detailed and accurate record is that of Mrs. Walsh's well, presented below:

Record of Mrs. Walsh's well, sec. 17, Grant Township.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	15	15
Quicksand	20	35
Red clay, gravelly and hard	22	57
Rock.		

SHERIDAN TOWNSHIP.

In Sheridan Township (T. 15 N., R. 12 E.) the wells are generally shallow, often getting an abundant supply in gravel at 12 to 20 feet, though occasionally bored 20 to 30 feet. No doubt a good supply of soft water from sandstone could be obtained within 200 feet. On the southeastern edge of the township are a few wells in rock, th

listance to rock ranging from 24 to 102 feet, as follows: In sec. 13, 24 feet; in sec. 24, on a hill, 102 feet; in sec. 35, 73 feet; in sec. 36, 50 feet.

BINGHAM TOWNSHIP.

In Bingham Township (T. 15 N., R. 13 E.) the hills are largely of till, which is not a good water bearer, and the wells on them, often 100 feet deep, enter the underlying Upper Marshall sandstone. The well of R. Harrison, in the southeast part of sec. 2, at altitude 879 feet above tide, penetrated 130 feet of drift and has a water level 60 feet below the surface. There was 80 feet of hard till and blue clay beneath which was 50 feet of fine sand or silt. In the valleys sandstone is struck at 25 feet or less and the drift is largely gravel. Wells are often obtained around Ubly in the gravel at 10 to 12 feet, while at Wadsworth they are 20 to 40 feet deep. At Ubly there is a bed of till under the surface sand and gravel which in some cases is underlain by another gravel bed extending to bed rock at 70 to 80 feet.

PARIS TOWNSHIP.

In Paris Township (T. 15 N., R. 14 E.) the drift is thin at the northeast corner, but increases in thickness to the southwest, where the rock may be struck anywhere from 40 to 100 feet or more. Sandstone underlies the whole township.

SHERMAN TOWNSHIP.

In Sherman Township (T. 15 N., R. 15 E.) most of the wells are shallow and chiefly in the sand or gravel of the old lake shores, for the underlying drift appears to be a heavy clay and the rock is shale, in which salty water is struck in limited amounts.

WHITEROCK TOWNSHIP.

In Whiterock Township (T. 15 N., R. 16 E.) conditions are similar to those in Sherman Township, and the best reliance seems to be on shallow surface wells carefully protected from contamination. There are springs along the bank of the old Lake Algonquin.

SAND BEACH TOWNSHIP.

In Sand Beach Township (T. 16 N., Rs. 15 and 16 E.) the drift is mainly clay except for sand on the surface, and varies in depth from a feather edge to 83 feet or more. The wells into rock are likely to be salty. The village of Harbor Beach, as indicated above, is supplied by pumping from Lake Huron.

SIGEL TOWNSHIP.

In Sigel Township (T. 16 N., R. 14 E.) are large surface deposits of sand and gravel, and shallow wells using surface water are common. Good water may be obtained from the underlying sandstone.

VERONA TOWNSHIP.

In Verona Township (T. 16 N., R. 13 E.) the wells are either shallow, with a depth of but 10 to 12 feet, or are over 40 feet. There is usually 40 to 45 feet of clay above the sandstone. Wells in the sand rock flow at an elevation of 4 to 5 feet above the lowest level. The following are typical records:

Well records in Verona Township.

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Muck and shell marl	5	5	Gravel	12	12
Clay	20	25	Hardpan	20	32
Gravel	5	30	Blue clay	7	39
Hardpan	15	45	Gravel	3	42
Sand rock	30+	75+	Hardpan	2	44
			Sand rock	16+	60+

The flowing-well water has a temperature of about 47° F. and a hardness of 5° to 6° on Clark's scale.

Wells put down to test the possibilities of water supply for a sugar factory in Bad Axe near the Pere Marquette Railroad tracks, in sec. 19, Verona Township, at an altitude of 756 feet, are all reported to flow at times after storms, etc. At the time of the writer's visit, however, only one was flowing. This had a temperature of 47°. These wells are 340 feet deep and have 46 feet of 7-inch casing, reaching probably to bed rock. The Bad Axe public supply is discussed above.

COLFAX TOWNSHIP.

In Colfax Township (T. 16 N., R. 12 E.), which includes the western part of the village of Bad Axe, the Marshall sandstone is struck at no great depth, the drift being usually 20 feet or less in thickness, but in sec. 19 the drift is 60 feet. A cherty limestone, with gypsum and shale in places, immediately underlies the drift, but the three have a combined thickness of only about 50 feet, thus making the depth to the Marshall sandstone about 70 feet.

OLIVER TOWNSHIP.

In Oliver Township (T. 16 N., R. 11 E.) there were many flowing wells, but most of them have failed, the failure being attributed in part to the draft made by the railroad water tank, in which the pipe was cut off below ground and the water allowed to flow into

e tank. No doubt the lowering of the ground-water level by tching has something to do with the failure. Wells in sec. 8 tain their water just above the rock at a depth of 50 to 65 feet. Elkton sandstone was reached at 25 feet, and the depth to rock 20 to 35 feet through secs. 20, 21, 22, 27, 28, and 33. Flows are t uncommon and have a temperature of 47.5° F. An interesting ature is reported from a well in sec. 36 only 13 feet in depth and arged with H_2S. When the wind is from the east the water becomes ack. By some change of relative head an iron-bearing or chalybte water may enter at such times.

WINSOR TOWNSHIP.

Winsor Township (T. 16 N., R. 10 E.) is a fertile, well-settled wnship full of wells, many of them deep. Some of those passing rough the Michigan formation are highly mineralized. A prelacial valley traverses the township from north to south, nearly llowing Pigeon Valley, and a limestone ridge with a steep escarpent toward this valley lies to the west of it, thus giving much ariety in the wells. Near Berne, in secs. 1 and 2, wells 30 to 40 feet eep obtain, just at the top of the rock, water which rises barely to he surface. In sec. 6, also, wells almost flow, or flow until midsumer. They are obtained from the rock at depths of 20 to 29 feet, the ock being entered at 7 to 16 feet. Wells are shallow in secs. 4 and and are liable to go dry. In sec. 7 wells 27 to 37 feet deep someimes flow and give a temperature of 49° to° 50 F. In secs. 8 and 9 he rock is from 2 to 38 feet from the surface, and in the latter secion wells 180 to 190 feet deep flow with temperatures of from 47° to 8°. Around Pigeon the drift is largely clay and reaches a depth of 0 feet. The lower part is slippery blue clay, which tends to close p the wells. Water is obtained from sandstone at about 120 feet. n secs. 13 and 14 dug wells 12 to 15 feet deep occur, but are liable o go dry. There are also wells 175 to 200 feet deep which flow. In ecs. 15, 16, 17, and 18 many wells are put to the limestone 24 to 40 eet, and shallow wells are usually obtained in secs. 19 to 26. In ecs. 27 and 28 they pass through a large amount of drift. One at chool district No. 1 struck rock at 74 feet, as shown in the following ection:

Record of schoolhouse well, sec. 28, Winsor Township.

	Thickness.	Total depth.
	Feet.	*Feet.*
ed or oxidized clay	12	12
lue clay	39	51
ardpan and bowlders	3	54
and and gravel	1	55
ardpan and bowlders	19	74
ate rock	12½	86½

In sec. 29, Winsor Township, wells range from 69 to 188 feet, the upper limit being the bed-rock surface. In sec. 30 bed rock is about 60 feet and wells are from 40 to 200 feet. In this southwest part of the township they are likely to be strong in sulphates. In the southern sections the drift is thick, being about 60 feet in sec. 31, 64 to 80 feet in sec. 32, 70 to 80 feet in sec. 33, 104 to 120 feet in sec. 34, and 73 feet, at Linkville, in sec. 35. In these sections the drift is very largely clay, and water is obtained at its base or in the rock.

FAIRHAVEN TOWNSHIP.

In Fairhaven Township and Bayport (Tps. 16 and 17 N., R. 9 E.) a heavy belt of sand, the Algonquin beach and dunes, is present, on which surface wells can readily be obtained. Back of it is an old muck swamp under the north end of which limestone sets in at a very few feet and water comes nearly to the surface, rising a little above when the quarries are not pumped and falling below when they are pumped. The temperature of these wells when flowing in the summer was 50° to 51.5° F. A flowing well on sec. 28 struck bed rock at 60 feet and terminated at 100 feet; temperature of water 51.5°. Most of the wells at Bayport are in the sub-Carboniferous limestone, which is covered mainly by sand.

CASEVILLE TOWNSHIP.

In Caseville Township (Tps. 17 and 18 N., R. 10 E.) is a belt of sand dunes east of which the soil and drift is mainly clay. An abundant, though highly sulphated, supply of water is generally found at the base of the drift. Wells which terminate in the Michigan formation or which are not cased through that group are often highly mineralized. When the wells are sunk into the Marshall sandstone, it would be better always to case off the supply from the Michigan formation. Bored or dug wells when over the line of pre-Glacial channels penetrate 70 feet or more of drift, but elsewhere rock is struck at less depth. In Caseville the water comes to within about 5 feet of the surface.

CHANDLER TOWNSHIP.

In Chandler Township (T. 17 N., R. 11 E.) there are good wells in the sandstone in secs. 1, 2, 3, and 4, rock being entered at about 25 feet. The deeper wells in sec. 4 have a head close to the surface. On the west side of sec. 5 wells begin to be brackish because of the gypsum, whose line of outcrop runs from this section to Soule. Wells in sec. 6 are shallow, in sec. 7 deep and saline, and in sec. 8 strongly sulphated, being drilled into the gypsum. They sometimes flow even when only 18 to 25 feet deep. In secs. 10 to 13 rock is entered at 30 to 37 feet and in sec. 14 at 40 feet, the drift being largely blue clay, but supplied with water beds at 12 to 18 feet in

14. Sulphated waters are struck at the top of the rock in secs. 17, 18, and 20 at about 30 feet. In sec. 19 a fair water was tained at 16 feet, but a well 45 feet deep was too highly mineral-d. In the southern half of the township wells in the drift are not ry reliable, and in several sections wells have been sunk to the arshall sandstone. There are springs on the banks of the Pinnebog sec. 26 and some dug wells 18 to 30 feet in depth. In sec. 33 is a l ridge flanked by gravel, in which very shallow wells are sometimes btained.

MEADE TOWNSHIP.

In Meade Township (T. 17 N., R. 12 E.) the Upper Marshall sand-tone is usually drawn upon and bed rock is sometimes practically at he surface. A series of sand and gravel ridges, which afford surface ater, traverses the township from the southwest to the northeast orners.

LINCOLN TOWNSHIP.

In Lincoln Township (T. 17 N., R. 13 E.) there are a number of hallow wells in gravel beneath blue clay. Those at Kinde run from 11 to 20 feet deep. Rock is struck in sec. 19 at 37 feet and in sec. 20 t 50 feet. In the northern part of sec. 22 a well 21.5 feet deep has vater which comes from sand under the clay within a foot of the urface. The well apparently has iron and organic matter derived rom the marsh.

BLOOMFIELD TOWNSHIP.

In Bloomfield Township (T. 17 N., R. 14 E.) the Lower Marshall andstone is struck at from 11 to 30 feet, though in secs. 20 and 22 the listance to rock is 40 feet or more.

RUBICON TOWNSHIP.

Rubicon Township (T. 17, R. 15 E.) is traversed diagonally by everal sand ridges parallel to the lake shore, which furnish surface vater at a depth of about 12 feet. The drift beneath is largely clay vith a scanty yield of water, and the wells which enter rock are liable to obtain salty water.

LAKE TOWNSHIP.

In Lake Township (T. 18 N., R. 11 E.) is a heavy belt of dune sand bordering the shore behind, which is a swampy area from which the surface rises back from the lake. Sandstone is very probably not very far down, though in sec. 26 the distance to rock is 40 feet. In sec. 32 are pits that suggest the presence of cavernous limestone or gypsum.

HUME TOWNSHIP.

In Hume Township (T. 18 N., R. 12 E.) the shore-sand belt i general conditions are much as in Lake Township. The drift in pla is but 5 to 7 feet, though in sec. 13 it reaches 32 feet. The only v that reports anything but clay before reaching bed rock is on sec. It strikes quicksand or silt at 12 to 14 feet. On sec. 28 is a flow well bored 40 feet. The distance to rock in sec. 31 is 30 feet about the same in sec. 35.

DWIGHT TOWNSHIP.

In Dwight Township (T. 18 N., R. 13 E.) sandstone is in plac the surface, and numerous wells are obtained from it at a dept 20 feet or less A flowing well on sec. 8 is 100 feet deep with a he 1 foot, the ground being 10 or 15 feet above the neighboring str Aside from the sand ridges the drift is generally a blue clay, th on sec. 35 a well is said to have passed through 20 feet of coarse g above the clay.

HURON TOWNSHIP.

In Huron Township (T. 18 N., R. 14 E.) are numerous wells w enter rock at depths ranging from 3 feet to 40 feet; usually the said to be through clay. In secs. 18, 19, and 30 wells are obtain gravel or sand just above the rock at depths of about 25 feet. A the Lake Huron shore there is a strip of country about 2 miles v where shale is penetrated immediately below the drift and yields water in scanty amount.

GORE TOWNSHIP.

In Gore Township (T. 18 N., R. 15 E.) the rock water is likel be somewhat salty and the supply from the drift scanty, since latter is largely clay. The best chance for water is at the junc of the drift and rock at 26 to 30 feet.

PORT AUSTIN TOWNSHIP.

In Port Austin Township (T. 19 N., Rs. 12 and 13 E.) rock is usu struck within 12 to 22 feet of the surface. In the village of Port . tin the shallow wells penetrate clay about 10 feet and gravel 3 obtaining water at the top of the rock.

WATER SUPPLIES OF THE NORTHWEST BORDER OF SAGINAW BAY.

By W. M. Gregory.

GENERAL STATEMENT.

There is a gradual rise from the shore of Saginaw Bay northwestward across Arenac and Iosco counties to the upper limits of the glacial lakes that once covered the region to an altitude about 800 feet above tide (Pl. IV). The lake plain is in places sand covered and barren. Clayey portions are rapidly becoming settled. In northern Iosco County there is a large sand plain standing 100 to 150 feet above the valley of Au Sable River, in which the water table is probably nearly as low as the stream, but as the country is unsettled no wells have been made in it, except along the borders. On the clay tracts wells are ordinarily obtained at less than 50 feet and often at depths 10 to 20 feet.

WATERWORKS.

Waterworks are in operation at Au Sable, Oscoda, and East Tawas, which draw their supply from Lake Huron. At Standish is a waterworks plant used chiefly for fire protection, which draws from wells and a small creek.

FLOWING WELLS.

LOCATION.

In the belt of lowland bordering Saginaw Bay from Pinconning to East Tawas flowing wells are numerous. Some of these are from the drift, but the larger number are from the rock. There are also deep wells drilled for brine some years ago when the sawmills had plenty of fuel for the manufacture of salt. These are located at East Tawas, Tawas, Harmon, Augres, Standish, and Pinconning. At East Tawas one of the brine wells flowed. At Tawas after plugging the wells and drawing the upper part of the casing, thus allowing water from higher levels to enter, flows have been obtained in wells in which the brine rose only to 30 feet below the surface.

There is another flowing-well belt running nearly parallel with the one just mentioned, from Mount Pleasant, Isabella County, to Rose City, Ogemaw County. The district lying between the two belts has occasional flowing wells, usually along stream valleys, but generally no flows can be expected, and in places water is difficult to obtain. The western flowing-well belt is discussed on pages 92–115, the present discussion being confined to the belt bordering Saginaw Bay and the district with few flows lying back of it.

The flowing wells are most numerous at three villages in the belt bordering Saginaw Bay, namely, Pinconning, Twining, and Tawas, the remainder being scattered or in small groups. Data concerning them are assembled in the table on the next page.

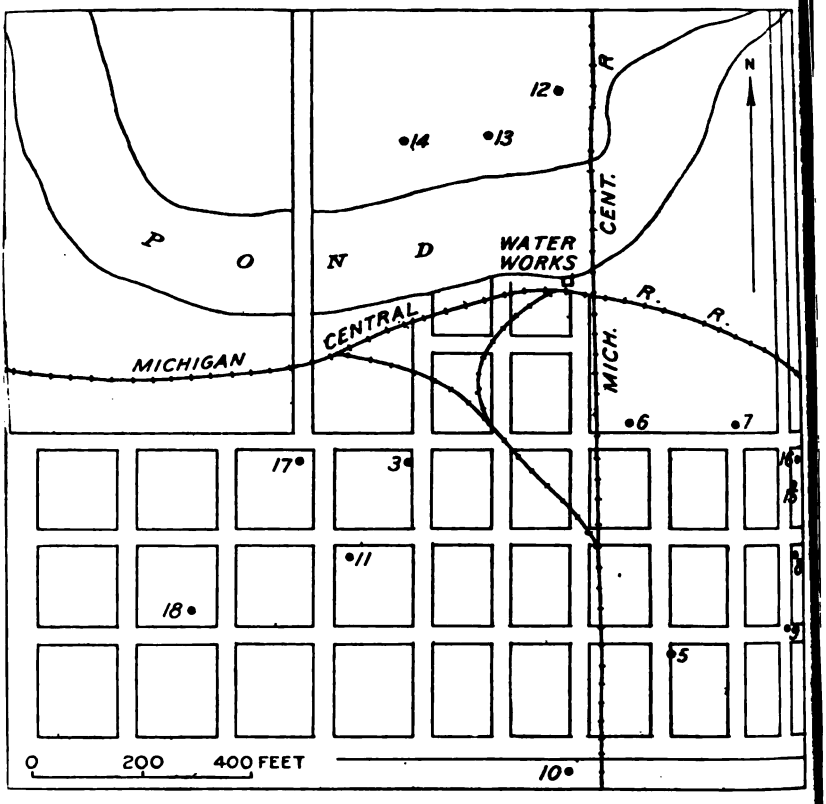
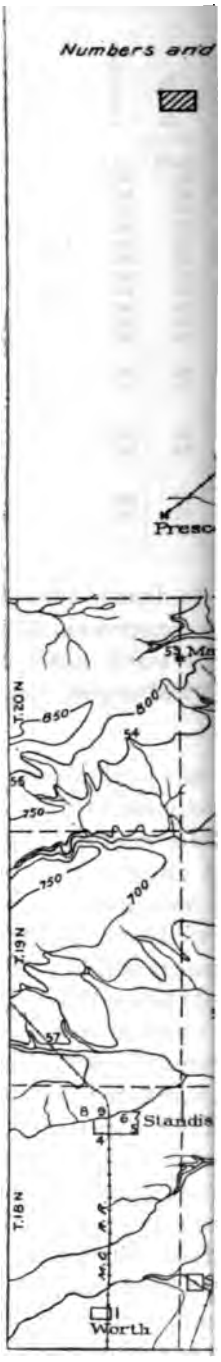


FIG. 54.—Map of Pinconning, Bay County, showing distribution of flowing wells.

PINCONNING.

General conditions in the vicinity of Pinconning are described under the discussion of Bay County, by W. F. Cooper. The detailed data in the table were collected by the writer in connection with other flowing-well districts bordering Saginaw Bay.

U. S. GEOLOGICAL SURVEY



Wells at Pinconning.

Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	° F.		
D. Markwart	596	56	540	597	0.1	.....	Hard	Weak flow.
Henry Shook	596	52	544	601	.3	51	Salty; hard	Decreased.
School	597	58	539	605	.9	51½	Salty	Drinking.
F. W. Klump	596	72	524	.....	.8	.....	Salty; hard	Store well; drinking.
W. A. McDonald	596	60	536	.....	.5	.....	Hard	Store.
F. W. Klump	595	53	542	.....	.9	.....	do	House use.
Louis Pelky	594	50	544	604	2	.....	.....	Just to rock.
Catholic Church	594	52	542	.....	.3	.....	Brackish, hard	Flow decreasing.
W. A. McDonald	596	48	548	.....	.9	.....	Salty	House use.
Stave mill	596	65	531	607	1	49½	do	Rock at 45 feet.
A. Grimshaw	596	60	536	606	1.5	.....	do	Flow decreasing; rock at 50 feet.
Wm. Davis	598	28	570	596	.....	.....	.....	Stopped flowing.
Ed. La Penie	597	42	555	.....	1	.....	Salty	Sand, 20 feet; clay, 22 feet; water from gravel.
Emery La Marsh	597	46	551	.....	2	48½	.....	House use.
M. Stevens	595	64	531	607	1	49	Salty; hard	Good flow at 60 feet; coal at 140 feet; salt water.
O. Sullivan	596	65	531	.....	.9	.....	Hard	House use.
Geo. Hartingh	597	59	538	.....	.6	.....	.....	Do.
Ed. Jennings	.....	65	.....	.....	.....	.....	.....	Rock at 55 feet.

he diameter of each of these wells is 2 inches. There are six other ·ing wells concerning which no data could be obtained owned by :tor Grosjean, Peter Collie, M. Doan, A. W. Fisk, J. Morris, and n Francis, respectfully.

TWINING.

he water supply of the village of Twining in Arenac County is from : wells, and the neighboring villages of Standish, Omer, Augres, and ner (Pl. V, *A*) have a like source of supply. In Twining the largest ıber of village wells have been developed, but there are many 'e wells scattered over Arenac, Iosco, and Bay counties. In Twin- the rock is covered by 12 to 20 feet of drift, which is largely clay ı bowlders of limestone and gypsum from the Michigan formation, ɔh is the bed rock of the region, outcropping at Alabaster and Har- ı on the shore of Lake Huron.

/ater is never obtained from the gypsum beds in the Michigan ıation except in a few cases where crevices allow a small amount ıercolating water. Where the gypsum beds are near the surface : holes are frequently found in places where the water has dissolved ınsiderable passageway, a few being found southwest of Alabaster. .eath the larger gypsum beds are the sandstone and limestone beds vhich the smaller seams of gypsum are frequently entirely dis- 'ed, and when these beds are opened by drilling through the gyp- ı plenty of water is found.

n the village limits the water supply is from thirty rock wells which 'e been drilled within the last twelve years and have been flowing

uninterruptedly since they were made. A slight decrease in vol during the summer months has been observed by some of the owners. The supply derived from these wells is valuable, and wells should be carefully piped and properly controlled so that unnecessary waste of the water would result, as it might cause per nent loss of head and volume.

It is necessary to case each well down to the rock to shut out bitter water which collects above the rock. The presence of this l

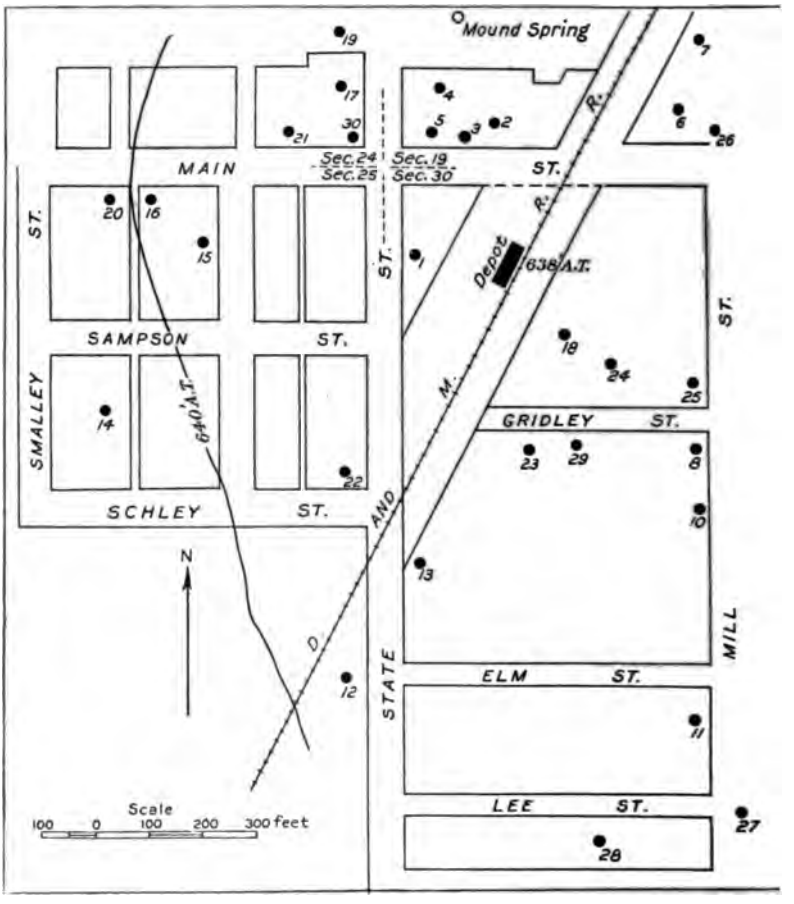


FIG. 55.—Map of Twining, Arenac County, showing distribution of flowing wells.

ter water in the drift often renders the supply from this source us for stock and unfit for domestic purposes. The rock wells affor abundant and suitable supply for all purposes, and failures to ob a flow have seldom occurred when the drilling was properly done. presence of sulphates in the water gives rise to deposits of calcium phate which tend to choke the pipe and decrease the flowage, but is not general enough to seriously interfere with the supply. The

A. • LARGE FLOWING WELL FROM ROCK, TURNER, ARENAC COUNTY.

B. FIRE-SERVICE TEST, ARCADIA, MANISTEE COUNTY.

Showing five streams from a single well under natural pressure.

rilling averages about $0.75 a foot, which is cheap for wells in the c, but higher than the price usually paid for obtaining flows from drift.

'he largest flow is 25 gallons a minute from a well (No. 6 of table) :he mill property of T. MacCrady. The flow of some of the wells ies at different times of the year. For instance, Mr. T. Reade's l (No. 14) ceased to flow during a drought in July and August, 4, while at the time of the writer's visit, which was four days after close of a week of heavy rainfall, there was a flow of 0.8 gallon a ute. Mr. F. L. Twining has had the same experience with a well). 5) which flows much stronger in the spring and late in the fall shows a noticeable increase several days after a period of pro-ged rain. In July, 1903, Mr. Twining's well at the store (No. 5) ed 10 gallons a minute, while in July, 1904, its flow was very small a pump was required. A number of other wells have shown a dency to decrease. At the Hotel Normal in July, 1903, the well l a flow of 3 gallons a minute, while in July, 1904, the water level 2 feet below the surface. That several of the wells have a com-n supply is shown by the decrease in the flow of wells Nos. 2, 3, and vhen in May, 1903, well No. 6 was allowed to flow for three days. July, 1903, Mr. George Dillon's well (No. 16) flowed nearly 10 gal-s a minute, but in July, 1904, the flow was very small and varied m day to day, its variations depending on the rainfall, according to se who had observed it carefully. The flow differs somewhat with character of the rock in which the well is drilled. If it is largely dstone, the supply is more uniform than where the beds contain siderable gypsum. In the latter case the water follows dissolved sages from the surface and frequently brings to the well silt and nt remains after heavy rains.

'he shallow wells which are deep enough to meet ordinary domestic ds furnish water high in sulphates and carbonates and are often te bitter when from near the top of the rock. Of the wells which v from the rock, the water highest in sulphates and carbonates nes from wells Nos. 1 and 9. In the latter the water was mixed h surface water for use in steaming, but has been discarded ause of trouble with boiler scale. In Mr. J. W. Jaynes's well (No. the water is so soft that it is used for laundry purposes without lition of the softening compounds that are necessary with much of water in this region.

Wells at Twining.

No. on fig. 55.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to.	Flow per minute.	Temperature.	Quality.	Remarks
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	° *F.*		
1	Hotel Normal [a]	639	76	563	642	.....	48	Hard	Hotel use.
2	J. March [b]	639	57	582	.....	.....	47	do	Domestic use.
3	E. F. White [c]	639	43	596	.....	.....	47	do	Do.
4	F. L. Twining [d]	639	33	606	.....	12	48	.....	
5	do. [e]	639	64	575	.....	.....	49	Hard	Store and house
6	T. McCrady (saw-mill) [f]	632	32	600	641	25	47	.....	Used in boilers.
7	B. W. Bodine [g]	632	28	604	649	10	46½	Soft	Used for steami
8	J. A. Patterson [h]	635	21	614	.....	2	47	.....	House use.
9	Stave mill [i]	633	52	581	635	5	51	Hard	Drinking.
10	Chas. Hinckley	635	25	610	.....	.5	49	do	House use.
11	Geo. Hollister [j]	636	32	604	.....	1	47	.....	Do.
12	E. Brush	636	26	610	636.5	.3	48	Hard	Do.
13	Chas. Bartlett [k]	636	28	608	.....	1.5	49	do	Do.
14	T. Reade [l]	642	26	616	.....	1.2	47	do	Creamery.
15	J. W. Jaynes [m]	639	42	597	.....	2	48	Soft	House use.
16	George Dillon [n]	640	46	594	641	1.8	47	.....	Do.
17	Wm. Monroe [o]	639	21	618	.....	1	48	Medium	Do.
18	Twining elevator	638	20	618	.....	.5	.....	.....	Drinking.
19	F. L. Twining	639	22	617	.....	.9	48	.....	Stock.
20	School [p]	642	60	582	643	3	48	.....	Drinking.
21	Stevens restaurant	639	78	561	.....	.....	.....	Hard	Well not used.
22	Mr. Hewett	638	22	618	.....	.....	.....	.....	
23	L. Brooks	638	37	601	.....	.....	47	.....	
24	Hub Mill	638	27	611	648	3	48	.....	
25	L. White	636	32	604	.....	1.5	46½	.....	House use.
26	J. E. Esler	633	51	582	.....	.....	46½	.....	No flow; 19 feet
27	J. Reade	633	60	572	.....	.....	.....	.....	Pumped.
28	T. Stall	639	.....	.....	.....	.6	.....	.....	
29	George Chubb	637	23	614	.....	1.5	.....	.....	
30	Fred Arno	639	20	619	.....	.4	.....	.....	

[a] Well not flowing in July, 1904; flow in July, 1903, 3 gallons a minute; water high in sulph
[b] Flow about 2 gallons a minute in July, 1903; no flow in July, 1904.
[c] Discharge of wells 2 and 3 decreased by well 7. Rock (bluish shale and gypsum) at 11 fee
[d] Blue shale at 14 to 16 feet; then thin bed of gypsum; at bottom thin bed of sandstone.
flow was made, the flow of wells Nos. 1, 5, 21, and 17 increased.
[e] Water used in a large butter room for cooling purposes. Mr. Twining says the large per
mineral salts in the water improves the quality of the butter. This well flowed 10 gallons a
1903; in 1904 only 1 quart a minute. Much stronger in spring and late in fall; some increase af
days of heavy rain.
[f] 16 feet to rock. Well controlled by check valves. In May, 1903, was opened and allowed
three days, lowering the head of Nos. 2, 3, and 5.
[g] Rock at 23 feet; water from beneath a shale.
[h] In 1903 good flow; decreased by well No. 11; drift 10 feet.
[i] Too hard for boiler use. High temperature of water caused by boilers located near well.
gypsum; head lowered by No. 11.
[j] Flow decreased soon after No. 7 was drilled. Allowed to flow freely for a few hours.
[k] Drift, 12 feet; blue shale, 5 feet; gypsum, 5 feet; shale, 5 feet; gypsum, 3 feet; sandstone
6 feet.
[l] Rock at 13 feet (gypsum and shale); water in sandstone.
[m] Flow decreased by well No. 16 on George Dillon's lot.
[n] The flow of this well ceased during the drought in June and July, 1904. At the time of t
visit, four days after a week of heavy rainfall, the well was flowing about 8 gallons a minute
[o] Rock at 17 feet (sandy shale rock). Water from sand veins at 19, 24, 30, and 42 feet.
[p] Flow decreased since 1903; it was then nearly 10 gallons a minute; rock at 21 feet.

TAWAS.

This area of flowing wells occupies nearly 1 square mile
shore of Saginaw Bay in Tawas, the county seat of Iosco Coun
56). Two miles west of Tawas there is a low moraine which
catchment slope of some of the wells. At East Tawas, 1 mile
east, flows can not be obtained, although water rises just to t
face in some wells near the lake shore. To the north and
Tawas flows are obtained on the plain between the town a
moraine.

ırea rock outcrops are entirely absent, but the first or upper ıtion is known, from the records of the deep brine wells, to ıe base of the Michigan formation and top of the Marshall

The sandstone yields abundant water when penetrated to the southwest, and possibly part of the supply for the may be derived from the same source. The Marshall sand-

FIG. 56.—Map of Tawas flowing-well district, Iosco County.

to the southwest from Tawas, and 5 miles south, at a test ıe quarry at Alabaster, it was reached at 90 feet and water he sandstone with sufficient head to fill the shaft.

't at East Tawas and Tawas is 80 to 120 feet in thickness. *ached at 84 feet in* Frank Black's well in East Tawas, and

in the same place on the property of the Michigan Brine Works rock is 100 feet from the surface. In Tawas the Wenona Salt and Lumber Company struck rock at 100 feet, and at the Bayside Hotel rock was found at 120 feet. In a cut on Dead Creek, in the western part of this village, is a hard compact clay containing minute shells, such as inhabit the lake, and some driftwood, overlain with 15 feet of lake sand and gravel. In several wells driftwood has been encountered at 50 to 75 feet. The drift material is not generally water bearing except at bottom where sand and gravel are found in thin layers. The wells are usually drilled by contract for a flow, the price averaging from $40 to $70, while some of the test wells which penetrate the rock some distance are made for $1 a foot without the pipe.

The total flow of 43 wells at Tawas is 137.3 gallons a minute. The strongest flow is from a well on the Blust estate (No. 34), which yields 19.3 gallons a minute. The flow is decreased in some cases by the escape of the water at a lower level, owing to corrosion of the pipes, while in other cases wells on lower ground have checked flows on higher ground. It is thought that the former is the cause of the decrease in flow of Joseph Minor's well, though possibly it may be drained by well No. 22 on the property of Mr. Davidson. The wells require frequent sand pumping and removal of the deposits inside the pipes. The Phelan well (No. 26) and German Lutheran Church well (No. 41) ceased to flow in the fall of 1903; after being sand pumped and cleaned, the flow returned to about the amount when the well was drilled. The wells which do not yield water readily are increased by a small blast of dynamite at the bottom. A greater flow in these wells following a prolonged season of rain is reported by some well owners, but not verified.

The quality of the water varies considerably with the depth of the well. It is common to find a soft water at a greater depth and evidently near the rock surface. The water in most wells over 90 feet in depth is soft, but in those less than 90 feet is usually hard and in some cases is so high in sulphates that it is unfit for domestic purposes, as at Grice's blacksmith shop (No. 11) and on the Blust estate. Following are analyses of water from some of the wells:

Analyses of water from wells in Tawas.

[Parts per million.]

	1.	2.	3.	4.
Sulphates	273	273	88	522
Hardness	616	536	321.6	600
Magnesia	Much.	.....	.....	Much.
Carbonates	180	140	190	95
Chlorides	173.4	120	81.6	204

1. Bayside Hotel. 2. Blust estate. 3. German Lutheran Church. 4. Grice's blacksmith shop.

wells have been drilled rather uniformly throughout the village, little deeper in the eastern than in the western part, where s reached at a higher altitude. The wells in the western part n 70 to 80 feet in depth, and supply a harder water than that of per bed, indicating a different source of supply. An examina- the above analyses and tests of several waters for hardness water bed supplying a hard water, beneath which is a bed sup- a softer water. The well owners are acquainted with these om the use of the water for laundry purposes. The lower bed ved to be supplied by water forced upward into the gravel and om the underlying bed rock of the Michigan formation, which localities supplies a soft water. Mr. Van Way, owner of Bay- otel, gives the following record of well No. 10:

Record of Bayside Hotel well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
.....	35	35
gravel	15	50
clay	30	80
gravel, some water, flow	15	95
.....	5	100
with streaks of shale	25	125

Record of Davidson flowing well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
.....	10	10
.....	50	60
.....	10	70
gravel	10	80

Gilbirth, a well driller, gives the following record for a flowing o. 29) on the property of G. A. Prescott:

Record of Prescott well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
.....	40	40
.....	5	45
.....	30	75
gravel	15	90

Wells at Towas.

No. on fig. 56.	Owner.	Elevation.	Depth.	Diameter.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*In.*	*Feet.*	*Feet.*	*Gals*	°*F.*		
1	N. C. Hartingh	590	104	2	486	.....	1.2	50	Soft	Flow has decreased.
2	John Bagley	592	86	2	506	602	.4	49	do	Flow from under clay bed; decreased.
3	Chas. Dixon	589	80	2	509	.....	.....	49	do	Crock well, drilled in bottom.
4	G. A. Prescott	592	106	2	486	572	.....	49	do	Rock at 98 feet; flow at 86 feet; pump well.
5	Court-house	589	146	3	443	.....	1.5	50	do	Sandstone at 20 feet; blue shale at 40 feet.
6	John Swartz	593	101	2	492	.....	.4	49	do	Domestic use; excellent water.
7	H. Woizeschke	590	93	2	497	.....	1.2	49	do	
8	Nelson Bradon	589	114	2	475	.....	2	49	.....	Domestic use.
9	E. D. Schlecter	592	90	2	502	.....	6	48	.....	Do.
10	Bayside Hotel	584	125	1½	459	594	2	49	Hard	Said to reach rock at 100 feet; cased, 40 feet; decreased; sulphates present.
11	Grice's blacksmith shop.	583	75	2	508	593	4	47	do	No change in flow; sulphates present.
12	M. E. Friedman	585	98	3	496	589	.4	49	do	Made in 1897; cost $50; decreased.
13	Wenona Salt and Lumber Co.	585	870	4	285	.....	.....	.....	do	Much H_2S; chlorides, medium; salt well; flows from upper beds; rock at 100 feet.
14	A. Grenney	588	87	2	501	594	1	49	Soft	Some CO_2 present.
15	F. Marzinski, sr.	589	85	2	504	.....	.5	49	do	Trace of sulphates.
16	G. L. Cornville	590	100	2	490	595	.9	49	Hard	Some chlorides; trace of sulphates; domestic use.
17	M. Patterson	590	100	2	490	.....	.5	50	Soft	
18	Henry Funk	590	90	2	500	.....	1	49	Hard	Domestic use.
19	Mike McGarry	592	90	2	502	.....	0	49	.....	
20	F. Marzinski, jr.	595	104	2	491	.....	.5	50	.....	
21	Lutheran Church (Rev. Emmel).	596	90	2	506	.....	1.5	49	.....	Drinking.
22	T. Davidson	585	80	2	505	.....	1	49	Hard sulphates.	Sand, 10 feet; clay, 50 feet; hardpan, 10 feet; gravel, 10 feet; water from gravel.
23	J. Hamilton	587	84	2	503	.....	6	48	Hard	Muddy before storms.
24	Heuston House	590	85	2	505	590	0	48	.....	Water just at surface.
25	O. Grice	590	95	2	495	.....	6	48	.....	
26	Wm. Phelan	590	105	2	485	.....	8	48	Soft	Made in 1890; slight decrease; hard water at 70-foot vein.
27	Dr. MacIntosh	590	90	2	500	.....	3	48	.....	No rock; clay, 40 feet; hardpan, 50 feet; gravel, 6 feet; 95 feet to flow.
28	E. B. Van Horn	594	104	2	490	604	4	49	.....	
29	G. A. Prescott	598	90	2	508	610	8	47	.....	See section (p. 277).
30	J. Nesbit (farm)	600	114	2	486	.....	5	48	.....	
31	City well	590	85	2	505	.....	1	47	Hard	Weak flow; supplies 4 houses.
32	Dr. Conant	589	95	1¾	494	.....	4	48	do	Water considered slightly cathartic; some chlorides present; sulphates strong.
33	F. Gauthier	590	70	2	520	.....	3.5	49	.....	Supplies 2 families; trace of sulphates.
34	Blust estate	588	60	3	528	598	19.3	48	do	Sulphates present.
35	W. D. Graham	589	84	2	505	.....	0	48	do	Sand, 12 feet; clay, 50 feet; sand and gravel, 20 feet.
36	J. M. Walker	590	59	2	531	.....	8	47	do	Sulphates strong.
37	Rev. J. Pierson	588	85	2	503	.....	7	48	do	Affected by No. 13; when casing was pulled well stopped flowing.
38	W. D. Wingrove	587	85	2	502	.....	4	47	Hard	Sulphates present.
39	G. H. Redhead	591	78	2	513	606	8	48	do	Flow checked; much iron carbonate; not good for laundry purposes; sulphates strong.
40	City public school.	594	76	3	518	.....	9	48	Soft	Drinking; flow decreased; trace of sulphates.
41	Lutheran school (Rev. Wuggazer).	592	90	2	502	602	9	48	do	See analysis above.
42	F. Ballotman	589	112	2	477	.....	3	49	do	Sand, 25 feet; gravel clay, [illegible] feet; sand and gravel, little water, 10 feet hard clay, [illegible] feet; coarse gravel [illegible] feet.
43	Chas. Zurek	588	90	2	498	596	1.5	48	do	
44	F. W. Schlecht	585	73	2	512	.....	3	47	Hard	Domestic use for 2 families.
45	Joseph Minor	586	75	2	511	.....	.....	.....	.....	Decreased; no flow at present.
46	Steve Klish	587	87	2	500	597	3	48	Soft	Made in 1897; no decrease.
47	Mr. Bolt	588	104	2	484	.....	2	48	do	Domestic use.

Wells at Tawas—Continued.

Owner.	Elevation.	Depth.	Diameter.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
	Feet.	*Feet.*	*In.*	*Feet.*	*Feet.*	*Gals*	°*F.*		
Mr. Malone (east of town).	590	68	2	522	.....	1	47	Hard.....	Sand, 14 feet; clay, 40 feet; hard-pan, 5 feet; gravel and sand, 9 feet.
M. Murphy.....	588	101	2	487	.....	3	49	Soft.....	Saloon.
Mr. Halleck (west of town).	.....	65	2	.....	.....	2	47	Hard.....	High in sulphates.

Wells in region north of Tawas.

Letter on Pl. IV.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Quality.	Depth to rock.	Remarks.
		Feet.	*Ins.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*		*Feet.*	
A	Andrew Arnold...	660	2	111	449	670	0.8	Hard..	108	Stock well; made in 1900.
B	Milo Stevens.....	663	2	157	505	667	.5	...do..	.....	Water bed at 155 feet.
C	C. Kruger.....	648	1½	40	608	.....	.....	.....	.....	Pump well.
D	George Bennett..	650	2	39	611	640	.....	.....	.....	Do.
E	August Letze.....	660	2	50	610	.....	.....	.....	.....	Do.
F	Chas. Green.....	653	2	59	594	.....	.....	.....	.....	Do.
G	August Colger....	648	2	40	608	.....	.....	.....	.....	Do.
H	E. T. Dowell.....	633	3	58	575	644	1.8	Hard..	57	
I	John McMullin...	665	2½	60	605	685	2.5	.....	62	All clay; made in 1903.
J	George Simms....	670	2	83	587	.....	2	.....	78	Water at 50 and 60 feet.
K	J. Miller.....	630	2	60	570	.....	.....	.....	.....	Pump well.
L	John Schrieber....	665	2	82	583	675	3	.....	82	Made in 1903.
M	Andrew Franks...	655	2	35	620	.....	.....	.....	.....	Pump well.
N	Philip Land Co...	615	2	90	525	.....	.....	.....	.....	Pump well; mostly sand.
O	Henry Goodale...	650	2	79	571	.....	[a] 2	.....	70	Water at 45 and 60 feet.
P	Mr. Sullivan.....	670	2	291	379	.....	1.5	Salt...	.....	Clay 52 feet; cased 70 feet.
Q	Mr. Pierson.....	690	2	78	612	.....	[a] 1.9	.....	40	
R	School house.....	702	2	110	692	712	1	.....	91	
S	W. Ames.....	703	2	115	588	.....	1.2	.....	96	
T	Mr. Gray.....	700	2	68	632	.....	1	.....	.....	Pump well; domestic use.
U	Mr. Robinson....	695	2	69	626	.....	1.3	.....	59	
V	John Grant.....	658	2	160	498	.....	.....	.....	.....	Through clay; no water.
W	Mr. Black (Tawas beach).	583	2	145	438	.....	.....	.....	83	Water just to surface.
X	Salt well.....	.....	.....	.....	.....	.....	.....	.....	.....	
Y	Chas. Conklin....	615	2	104	501	.....	.....	.....	84	No flow.

[a] Flow estimated by driller.

MISCELLANEOUS WELLS.

Scattered wells (mainly flowing) on the northwest border of Saginaw Bay.[a]

Number on Pl. IV.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	E. Sack.....	615	.....	.....	605	.....	.....	Hard...	Pump well.
2	Bradley farm.....	590	105	485	608	1.9	49	.....	Rock at 30 feet.
3	E. Butler.....	592	60	532	.....	.9	48½	Hard...	Domestic and stock.
4	Primary school, Standish.	626	50	576	.....	.....	.....	.....	Just flows; high in sulphates.
5	High school, Standish.	626	230	396	632	1	48	.....	Not flowing now.
6	Court-house, Standish.	626	258	368	.....	.....	48	.....	Flowed in 1893; not flowing now.

[a] The diameter of all the wells is 2 inches except the following: Omer village, 1½ inches; August Badour, 3 inches; *James Daley, 1½ inches*; N. Knight, 1 inch.

Scattered wells (mainly flowing) on the northwest border of Saginaw Bay.—Contin

Number on Pl. IV.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*F.*		
7	A. Forsythe	628	85	543	.....	1	48	.....	Barn use; rock at 40
8	M. M. Milling Co.	625	78	547	631	1.	48	.....	Near boilers.
9	James Norn's mill	626	1,900	276	.....	12	50	.....	Water has salt and H
10	J. Larch	591	101	490	.....	9	48	Salt	Rock at 8 feet.
11	F. Menzer	610	148	462	609			.....	Rock at 29 feet; no f
12	Omer village	611	350	261	618	1.9	49	Hard	Rock at 21 feet; su hotels.
13	H. Ullman	604	342	262	624	10		.....	Rock at 22 feet.
14	W. Mackin	608		592	.....			.....	Dug well in rock.
15	J. Ryland	601	200	401	631	3	49	Hard	Rock at 12 to 18 feet.
16	Mr. Bradley	586	65	521	566			...do	Pump well; rock at 3
17	August Badour	586	301	285	611	3.5	48	...do	Formerly bath house
18	E. C. Cole's store	587	126	461	.....	2		.....	Rock at 30 feet; supp and house.
19	F. D. Noggle	587	29	558	587			.....	Just flows; decreased
20	Geo. Grimore	590	108	482	.....	2.5	48	.....	Rock at 28 feet.
21	E. C. Cole	595	322	273	611	8.2	48	Hard	Rock at 60 feet; house.
22	Wm. French	600	315	285		3.2	..	.....	Rock at 20 feet.
23	Harmon salt well	587	.....	.....	587			Bitter	Just flows.
24	Mrs. Peggel	608	146	462		2.		Hard	Rock at 44 feet.
25	Ed Mosher	622	83	539		.8		...do	Rock at 8 feet.
26	J. Pollock	624	57	567	629	2.	48	...do	Rock at 7 feet.
27	J. McCready	622	83	539		.8	..	...do	Rock at 10 feet.
28	J. Pollock (barn)	625	65	560		.2	48	...do	Do.
29	Mr. Swartz	650	240	410	665	12	49	Medium.	Rock at 27 feet; stop ing in 1904.
30	Mr. Reade	630	39	591	625			Hard	Rock at 5 feet; pump
31	Mr. Campbell	631	17	614				Bitter; hard.	Rock at 14 feet; pum
32	J. Barr	638	28	610	631	.....	.....	.....	Unfit for use; rock a
33	W. Aigens	650	25	625	.....	.....	.....	Hard	Pump well; rock at
34	H. Newman	640	140	500	655	2.5	49	...do	
35	Mr. Eymer	638	105	533		1.1	.....	...do	Rock at 40 feet.
36	Public school, Turner	642	130	512	652	1.8	49	...do	
37	S. Churchill	638	10	628	.....	.....	.....	Bitter	Rock at bottom; pu
38	J. Clukey	625	300	325	.....	3	50	Hard	Rock at 30 feet.
39	Village well, Turner.	635	300	335	640	12	50	.....	See cut; rock at 40 f
40	Young Bros	630	53	577	.....	.....	.....	Hard	Pump well; stock mestic.
41	Philip Rosenthall	640	105	535	653	2.3	48	...do	Rock at 26 feet; s domestic.
42	Sam. Rosenthall	640	104	536	658	2.5	49	...do	Rock at 21 feet; s domestic.
43	M. Siebeck	640	40	600	.....	.....	.....	.....	Pump well; drift, g clay.
44	S. B. Dryer	670	19	651	660	.....	.....	Hard	Pump well; dug.
45	T. Applin	630	250	280	645	15	50	Medium.	Rock at 20 feet; salt
46	J. Henry	650	115	435	.....	.....	.....	Salt	Just to rock.
47	H. McGrady	629	350	279	.....	2.5	....	Hard	Rock at 115 feet.
48	N. Johnson	640	139	501	.....	.....	.....	.....	Rock at 115 feet; no
49	Emery Junction Hotel.	677	40	637	647	.....	.....	.....	No rock; little wate
50	J. Curtiss	770	180	590	.....	.....	.....	.....	Rock at 40 feet; 2-in no flow; little wat
51	George Koyl	730	40	690	642	2.8	48	Medium.	All clay.
52	James Daley	738	100	658	.....	.....	.....	Hard	Brown clay 20 feet; 40 feet; sand 10 f pan 30 feet. Pum
53	Chas. Jones	810	60	750	.....	.....	.....	.....	Hard clay 14 feet; water 10 feet; cla sand and grave Pump well.
54	N. Knight	740	49	591	.....	.....	.....	.....	Clay 14 feet; remair Pump well.
55	Jas. Thompson	795	165	630	.....	.....	.....	.....	Clay 40 feet; sand a 20 feet; clay 30 f and gravel 75 fee well.
56	Robert Garner	618	78	540	.....	.....	.....	Soft	Rock at 14 feet; no
57	Old coal shaft	760	106	654	.....	.....	.....	.....	Flow from top of s Sand 20 feet; cla rock at 30 feet.
58	Black's test well	595	135	460	.....	.....	.....	.....	Rock at 57 feet; no

MISCELLANEOUS VILLAGE SUPPLIES.

The tabulated data on wells and villages and near country post-offices, presented below, were obtained chiefly by correspondence:

Village supplies on northwest border of Saginaw Bay.

Town.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alger	Driven wells	.....	15	100	20	80	.....	Small.
Arenac	do	.....	8	50	14	14	− 5	Do.
Augres	Dug and drilled wells	16	12	220	16	180	+15	None.
Maple Ridge	Open and driven wells	.....	12	45	35	35	.....	Small.
Melita	Driven wells	.....	18	50	14	14	− 5	
Moores Junction	do	.....	15	50	35	45	−15	Do.
Omer	do	20	15	104	40	40	+ 2	Do.
Pine River	do	28	12	138	30	138	+10	Do.
Saganing	do	70	6	70	20	20	− 8	Do.
Standish	Driven wells, and creek	40	12	350	.....	50	+ 8	None.
Sterling	Driven wells	.....	14	48	24	.....	−14	Small.
Au Sable	Lake Huron by waterworks	.....	.....	.....	.....	.....	.....	
East Tawas	do	.....	.....	.....	.....	.....	.....	
Hale	Dug and driven wells	.....	10	80	40	40	−35	Do.
Oscoda	Lake Huron by waterworks	.....	.....	.....	.....	.....	.....	
Siloam	Dug and driven wells	.....	12	33	33	33	−25	Do.
Whittemore	Driven wells	60	20	60	40	60	−20	Do.

WATER SUPPLIES OF OGEMAW COUNTY.

By W. M. Gregory.

GENERAL STATEMENT.[a]

Ogemaw County, of which West Branch is the county seat, lies east of Roscommon County. The elevated moraine which crosses the southeast part of Roscommon County continues northeastward, passing a little east of the center of Ogemaw County, leaving the county at its northeast corner. There is an elevated gravel plain on the northwestern face of this moraine, which at one time was occupied by settlers, but has been abandoned because of the failure of crops in dry seasons. The distance to water on this gravel plain ranges from 10 to 15 feet near the Roscommon County line to about 100 feet in the vicinity of the moraine from Beaver Lake northeastward. On the moraine there are very few residents, and the water table appears to lie at great depth, for the drift is very loose textured.

Southeast of this large moraine are the flowing-well districts of Rose City and West Branch, which stand in recesses in the moraine. There is a broad gravel plain leading from near Rose City and Lupton southward along Rifle River, where the water table lies only a few feet below the surface, but in which there are few settlers.

[a] By Frank Leverett.

In the eastern range of townships is a fertile till tract with gently undulating surface which has as yet but few settlers. Wells are obtained at depths from 20 to 75 feet.

There are exposures of rock along Rifle River in the southern part of the county, but the wells, both flowing and non-flowing, usually obtain their supplies from the drift. One well at Rose City entered the rock and got only a weak flow. Others at West Branch may have reached the rock, and two deep borings near Edwards Lake entered rock.

MISCELLANEOUS VILLAGE SUPPLIES.

At Prescott there are wells ranging in depth from 18 to 75 feet, in which the water stands 12 to 20 feet below the surface, coming from sand beds in the clay. Both open and bored wells are in use.

At Lupton, which stands in the valley of Rifle River, the wells are 20 to 50 feet in depth, and are largely through gravel and sand.

At South Branch, in the eastern part of the county, on the inner border of the large moraine, wells are driven to depths of 20 to 30 feet and obtain abundance of water.

At Edwards post-office, in the southwestern part of the county, the wells are from 6 to 50 feet in depth, the largest supplies being from 35 to 50 feet. Dr. A. C. Lane reports several test borings for coal. One at the south side of Edwards Lake in sec. 29 struck sandstone at 205 feet, and penetrated rock of various kinds for 33 feet. Another near Chapman Lake struck sandstone at 190 feet and continued to a depth of 400 feet. A fresh, soft water was struck at 202 feet, which had a head of 8 feet. A third well, 214 feet in depth, on the east side of George Lake, did not reach rock, but found a flow of fresh, soft water yielding a barrel a minute.

Plans have been made to install a waterworks plant at West Branch in 1906, the supply being taken from flowing wells northwest of the village. These wells discharge into a reservoir from which water will flow by gravity to the village, a distance of about 2 miles.

FLOWING WELLS.

WEST BRANCH AREA.

Location.—The flowing-well area of which West Branch is the center (fig. 57) embraces 2½ square miles on the headwaters of the West Branch of Rifle River. This district is located in a recess along the eastern side of one of the stronger moraines of the Saginaw ice lobe. The actual extent of the area, outside of the above city limits, has not been determined, but it has been traced north and south along the eastern slope of the moraine, and may connect with the well-developed area at Rose City. An almost continuous belt of springs occurs at the edge of the high hills between West Branch and Ogemaw

ngs station, at which place the principal spring flows about 13 ons a minute. Part of this water comes from loose drift on top he clay, while the larger share is from beneath a clay bed which been opened by small creeks working back into the hills. This dition of abundant springs is present about the western edge of entire area and the flow of water is in proportion to the extent t the creeks have worked back their heads.

Vells.—At present (August, 1904) the number of wells in the gen- . district is 119, of which 106 have fair flows. Of these, 102 flows within the village limits of West Branch. The wells are all 2 nes in diameter except Nos. 12, 17, and 27, which are 1½ inches. v wells are pumped and the flowing wells are utilized very gen- lly for stock farms, creamery, domestic use, laundry purposes, a for steaming, and one in a brewery.

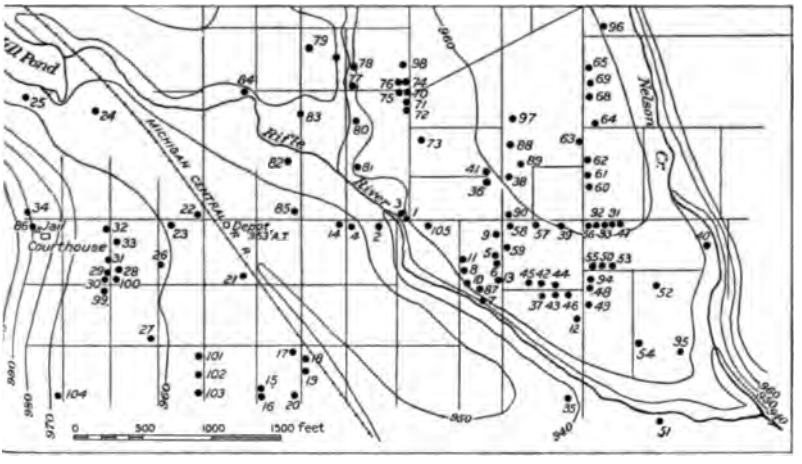


FIG. 57.—Map of West Branch, Ogemaw County, showing flowing wells.

The pioneer well was made by E. V. Goodell in 1880 by driving a nch pipe to the first water bed at 30 feet and later to the 80-foot d; the supply has decreased since drilling. The number of wells s increased rapidly, and with the increase some of the shallow wells ve ceased flowing entirely. The pressure of the water is sufficient a few cases to warrant piping to the second floor of a dwelling, d hydraulic rams are used in several cases to force water into chens.

The cost of the wells is somewhat less than in other regions, rang- g from $40 to $80, the low price being due to the slight depth of e water bed and to the use of casing in the deeper wells only. at the supply is valued the large number of wells show, but only a few instances are check valves used, the large majority of the lls being allowed to flow full capacity throughout the entire year.

This wasteful practise is believed to be the cause of the decrease of the flow shown in the past two years.

Flow.—The total flow from 106 wells is about 610 gallons a minute, of which 540 gallons are from wells within the limits of West Branch. The strongest flow is 60 gallons a minute, on the property of C. J. Blakeley (No. 22), and another large flow is at the West Branch brewery of Mr. A. M. Schieke (No. 40), where the combined flow of three connected wells is 156 gallons a minute. Many of the flows from the upper water beds have been decreasing for the last three years, this decrease being noted in many wells that the writer saw in 1903 and 1904. In some cases the decrease has been due to sand filling the pipe, in some to deposits of iron carbonates or other incrustations, and in some to the overdrawing of the supply by the drilling of recent wells. If wells were checked and controlled the supply might be available longer.

Water beds.—The water beds in this locality have been thoroughly exploited, especially the upper ones. The well drillers find that they are not as uniform as at Rose City. Their thickness is often 20 to 30 feet, consisting of gravel or coarse sand interbedded with clay. The coarser material is generally at the bottom, while at the center quicksand has been so abundant as to cause some delay in drilling and to prevent the use of the common form of jetting drill which is usually employed in drift wells. The thickness and extent of the first water bed is shown by well No. 22, at the livery barn of C. J. Blakeley, which was 65 feet at first, when it drew the water level down on all wells in the upper bed, some of these especially affected being Nos. 23, 32, 31, 30, 100, 33, 101, and 102. Doctor Newman's well, No. 23, did not flow after No. 22 reached 65 feet, but when the latter was cased to 108 feet and drilled to 165 feet the former regained a small flow. Later it was drilled to 130 feet, the level of the third water bed.

The first water bed in West Branch is about 40 feet from the general surface and some 25 feet thick. Its elevation above tide is about 920 to 945 feet. In the eastern part of the village the upper bed is somewhat lower and supplies the brewery well (No. 40) which has partly drained wells Nos. 47, 92, and 93. The group of wells directly south of the depot seems to reach a second water bed at a lower elevation, the drillers there finding a hard clay, varying from 20 to 30 feet in thickness, beneath which is obtained the supplies for wells Nos. 7, 91, 97, and 105. At the present time the second water bed is the source of a better supply than is obtained in the upper beds. The third bed, with a general elevation of 430 feet is the source of the strongest supply of the area. From it comes the supply for the wells of Stephen Weigers (No. 14), Ogemaw Bank (No. 85), C. J. Blakeley (No. 22), and Gale Lumber Company (No.

n several of the wells in this bed drift coal is found, coming he coal series of the Michigan formation, which outcrops to ıth and east. The greater supply and pressure of the water he lower bed is due to the presence of the Michigan forma- the east. At the West Branch Bridge over Rifle River, due ıst of this area, outcrops of the early Carboniferous limestone ndstone occur at an altitude of 785 feet above tide, and as ;er water beds are 790 feet above tide this seems a case where k cuts off an escape of the water at lower levels.

hment area.—The catchment area for the West Branch wells ıe loose drift material which constitutes the land to the north est, having an elevation of 1,200 to 1,300 feet above tide. esence of springs and lakes on the drift plains where the clay to the surface is due to the large amount of ground water in rous material and the small run-off. A part of the supply at w Springs can readily be traced to the water following clay h the drift down to lower elevation, while the larger supply ı between clay beds at greater depths.

perature.—The temperature of the wells averages nearly 48°, higher than the mean annual temperature of West Branch. mperature of the Gale Lumber Company's wells (Nos. 24 and the same, although there is a difference of 89 feet in their . The shallow well has 25 feet of pipe exposed, while the one has none. The exposure of 15 feet of pipe may account emperature higher than normal in the wells of Joseph Mer- o. 1) and at the village park (No. 3), while representative atures for that depth are in adjacent wells of Frank Smith and the Episcopal Church (No. 105). The difference between and soil temperatures (5.5°) is larger than in some experi- and observations elsewhere, but may be due to the blanket- ect of the heavy winter snow. The temperature of the springs maw Springs station, on the Michigan Central Railroad, north st Branch, in July, 1904, was 47°, which agrees with similar at Rose City.

:.—The table on the next page gives data of wells at and near Branch.

Wells in West Branch area.

WELLS AT WEST BRANCH.

No. on fig. 57.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—[a]	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F*			
1	Joseph Merrik	950	34	916			49		$22	Flowed 6 gallons a minute in 1903; drained by No. 105 in 1904.
2	Frank Smith	948	34	914		2	47½		25	Store and blacksmith.
3	Village park [b]	950	34	916		3	49			Water trough.
4	A. C. Irons [c]	952	35	917		3		Soft		At store.
5	A. C. Irons	955	52	903		7		do		Domestic use.
6	A. L. Shirgley	955	90	865		18	49	do		
7	James Barker	940	90	850		15		do	72	Barn and house.
8	Mrs. McKenna	952	80	872		1				Water has small amount of iron carbonate.
9	Mr. Banasso	956	50?	906		2	47	Soft	60	Domestic use.
10	F. Smith	950	81	869		.3	47½			Do.
11	Mr. Birdsall	953	82	871		1.7			60	Water has CO_2; corrodes pipe and tin dishes.
12	E. V. Goodell	953	80	873						Made in 1888; 1.5-inch; weak flow.
13	Chas. Raymour	952	92	860						Not flowing.
14	Steven Weigers [d]	953	160	793		25.7	49½		375	Carefully piped and controlled.
15	Mrs. T. L. Lowenzo.	965	45	920		1.2	48½		40	Not flowing in 1903, but after sand pumping in 1904 good flow.
16	C. E. Camp	965	75	890		7	48			Reduced to 1 inch.
17	C. W. Longwell	960	85	875		1.2	49			Well 1.5-inch; much algæ in water.
18	L. Walters	958	86	872		10.5		Soft	70	Fountain and fish pond.
19	Geo. Alexander	958	85	873		12	47½	do		Domestic use.
20	Alex. Brigham	964	90	874		1	47½	do		Decreased by No. 16; much iron carbonate on pipe.
21	McCannond Wood	953	151	802		3			150	Fountain and livery barn.
22	C. J. Blakeley [e]	953	165	898	963	60	47½	Soft	180	Drift coal in well.
23	Doctor Newman	958	130	828		3.7	48	Salt		Original flow at 60 feet; lowered by No. 22.
24	Gale Lumber Co. [f]	953	165	888	978	12.7	46½	Soft	100	Drinking.
25	Gale Lumber Co.	955	76	889	977	6	46½		50	Drinking and steaming.
26	D. McCannon	960	125	835		1.5	47	Soft		Livery.
27	H. Buckle	963	100	863		1	49	do	82	Domestic use; well 1.5-inch.
28	I. Unger	965	170	795		2	48	do	105	Domestic and stock.
29	John Gauf	966	45	921		4	47			Flow decreased since 1903.
30	Chas. Ross	966	45	921		3				Weak flow in 1903; no flow in 1904.
31	Chas. Wilson	967	45	922						Weak flow.
32	Ira Mitchell	968	45	923		1			40	
33	U. V. Guilford	967	80	887		1.2	49			Decreased since 1903.
34	Catholic Church [g]	990	30	960		1.8		Hard	100	Not suitable for laundry.

[a] All wells flow unless otherwise indicated, but the head can not be measured in those with goosenecks.

[b] This well was made in eight hours by hand with a clay auger and driving pipe in 1899. The following is the record:

	Thickness (feet).
Sand and gravel	4
Solid blue clay	47
Water gravel	1

[c] Wells No. 1 and No. 3 have 15 feet of pipe exposed above the surface. This accounts for high temperature.

[d] Supplies butcher shop and grocery store with a large butter room in basement; also piped to living room on second floor; made in 1899.

[e] Made in 1900 and is cased 108 feet. Is said to flow 2,000 barrels in twenty-four hours (probably an overestimate). First water at 65 feet; for a time supply was drawn from a 95-foot vein; later well drilled to 165 feet. This well is No. 164 in Water-Supply Paper No. 102, United States Geological Survey.

[f] The following is the record of this well:

	Thickness (feet).
Clay	10
Sand	15
Clay	50
Sand and gravel	5
Clay	20
Sand, small pieces of coal	5
Hard blue clay	50
Gravel, coal fragments	10

Water at 80 and 160 feet.

[g] Drilled to 130 feet; no flow; pipe pulled back to vein at 30 feet.

Wells in West Branch area—Continued.

WELLS AT WEST BRANCH—Continued.

ıer.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
	Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			
'emetery.	940	110	830	.....	3	....	.....	$92	Small fountain.
nbert....	958	14	944	.....	.....	....	.....	.....	Weak.
ıbar.....	955	42	913	.....	2.5	47½	.....	.....	Decreased by No. 42.
en.....	961	15	946	961	.5	....	.....	10	Weak flow; much CO_2.
eke.....	960	53	907	.....	.8	47½	.....	.....	House; piped to barn.
eke[a]	950	44	906	.....	156	47½	.....	100	3 wells connected and fountain.
v.....	960	45	915	.....	.9	....	.....	35	Decreased since 1903.
.ney.....	955	45	910	.....	3	47½	.....	35	Domestic use.
hugley...	954	45	909	.....	1.8	47	Soft.....	35	Do.
gan	955	30	925	.....	.....	....	.....	.....	Flowed in 1903; not in 1904.
effler.....	955	35	920	.....	.....	....	.....	.....	Do.
itton.....	953	50	903	.....	.....	....	.....	.....	Ceased to flow.
.....	960	50	910	.....	8.5	49	.....	.....	Domestic use.
ik.....	956	50	906	.....	.....	48	Soft.....	.....	Weak flow.
inder[b] ...	953	48	905	.....	12.2	47¼	.....	.....	Domestic and stock.
Sams....	957	40	917	.....	1	48	.....	.....	
lford.....	938	50	888	.....	3	....	.....	42	Large stock farm.
.....	953	60	893	.....	12	....	.....	.....	Stock.
igis.....	957	90	867	.....	12	48	.....	70	Do.
s.....	952	95	857	.....	3.5	....	.....	.....	
ry.....	958	50	908	.....	1.5	47	Soft.....	40	Domestic use.
dy.....	962	50	869	.....	2	....	....do...	40	House and fountain.
hitman...	959	90	869	.....	3	....	.....	.....	Domestic use.
gor.....	958	100	858	.....	.....	48	Soft.....	.....	Pumped.
ınard.....	955	.....	.....	.....	.....	....	.....	.....	Do.
e.....	963	50	913	.....	1.5	....	.....	.....	Domestic use.
ırton.....	962	30	932	.....	7.5	48	Hard ...	22	Good drinking water; unfit for laundry purposes.
glish.....	961	60	901	.....	3	47¼	.....	80	House and fountain; flow decreasing.
iller.....	962	60	902	.....	1.6	47¼	.....	.....	Domestic use.
ıler.....	963	45	928	.....	3	47¼	.....	.....	
'.....	964	45	919	.....	.....	....	.....	.....	Pumped.
gor[c]	.....	60	.....	.....	.....	....	.....	.....	1 mile south of village post-office; pumped.
'ry.....	.....	185	.....	.....	39	47	.....	75	Stock farm south of village.
ıwen.....	953	30	923	.....	8	....	Hard ...	.....	Water has much iron carbonate.
(?).....	952	50	902	.....	.....	48	.....	.....	Domestic use; weak flow.
kes.....	953	45	908	.....	31	....	Soft.....	.....	Do.
.....	953	90	863	943	.....	....	.....	.....	Pump well.
;r.....	953	75	878	.....	.....	48	Soft.....	.....	Weak flow.
ɔp.....	952	80	872	.....	.....	....	.....	.....	Well clogged with sand.
lell.....	953	75	878	.....	.5	49	Soft.....	.....	Weak flow.
.....	952	45	917	.....	1.5	47½	....do.....	.....	Flow decreased since 1903.
iith.....	952	90	862	.....	1.2	48	.....	.....	House and barn.
.....	949	60	889	.....	1.5	48	Hard	.....	Domestic: not suitable for laundry use.
;d.....	950	60	890	.....	1	47½	....do.....	.....	Decreased by No. 77.
.....	953	90	863	.....	.....	....	.....	.....	No flow; pump well.
.....	943	80	863	.....	1.8	48	Soft.....	.....	Domestic use.
ɔds.....	951	75	876	.....	1.5	48	....do.....	.....	Supplies house and barn.
itter.....	948	40	908	.....	3	47½	....do.....	.....	Supplies barn; much CO_2.
ırp.....	946	58	888	.....	1.8	48	....do.....	.....	Ram used to raise water to house.
'ner.....	949	60	889	.....	2	....	.....	.....	Weak flow; medium soft.
Bank.....	954	175	779	.....	8	....	.....	.....	Strong flow; piped to second floor.
il.....	992	182	810	.....	.....	....	.....	.....	
:tory.....	950	40	910	.....	5	....	.....	.....	Butter room and for steaming.
on.....	962	30	932	.....	2	....	.....	.....	2 wells same depth; medium hard.

in brewery satisfactorily. There are three wells 20 feet apart, which lowered head in 1 93. The owner, A. W. Schicke, states that water contains magnesia and plenty of CO_2. ɔdes iron pipes and tinware rapidly. No decrease in supply has been noted.

; to first water and continued through water-bearing sand to 108 feet without increase in

uth of court-house; penetrates following beds:

	Thickness (feet).
.....	30
.....	8
.....	2

Wells in West Branch area—Continued.

WELLS AT WEST BRANCH—Continued.

No. on fig. 57.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	° *F.*			
89	G. Day	962								
90	E. Evans	958	30	928		6.5?		Hard		Much sediment in water.
91	J. Bitters	961	51	910		1.5	48			Decreased since 1903.
92	Mr. Tartman	962	50	912		1.5	48			Supplies house and barn.
93	E. Clark	961	52	909		1.1	48½	Soft		Domestic use.
94	E. Shrively	955	60	895		.1				Decreased since 1903.
95	Lumber Co.	951	60	891		.5	48			Stock.
96	T. Wilder	961?	72	889						Pumped.
97	Mr. MacKinson	963	90	903	951					Pump well.
98	E. Blundell	955	45							Flowed in 1903; pumped in 1904.
99	Joe Reminder	968	80	888		4	48			Made in 1904; domestic use.
100	E. Hutton	966	72	894		2				Decreased by No. 22.
101	Mrs. Gray	958	73							Decreased by No. 22; no flow.
102	D. E. Marsh	958	116	842		2		Soft		Not good for drinking; muddy.
103	Jas. Lambert	958	70	888		.5		do		Decreased since 1903.
104	Joe Walters	969	65	894		4	48	do		Made in 1904.
105	Episcopal Church	950	40	910		3	47½	Medium.		Drained by well No. 1.

WELLS NORTH OF WEST BRANCH.

Township N.	Range E.	Section.	Owner.	Elevation.	Depth.	Flow per minute.	Temperature.	Quality.	Remarks.
				Feet.	*Feet.*	*Gals.*	°*F.*		
22	2	18	W. Tallman	1,043	45	1	48½	Soft	Stock and domestic use.
22	2	7	do	1,045	50	10	48	do	Domestic use.
22	2	17	Wm. Moss	1,030	62	1.5	48	do	All clay.
22	1	24	A. Ford	953	34	3	47	do	Quicksand and clay on top.
22	2	8	Jas. Moss	1,040	80	4	47		Stock and house use.
22	2	7	D. Webster	1,042	60	3			
22	2	18	L. Carr	1,000	60	1	48	Soft	Dairy and house use.
22	2	7	School	1,100	50	3	49	do	Drinking fountain.

WELLS SOUTH OF WEST BRANCH.

22	2	31	O. B. Stevenson		20 30	10	47½	Soft	Two flows; water rises 2 feet above surface.
22	2	31	Mrs. Place		75	5	48	do	Sand 28 feet; remainder clay; water rises 1 foot above surface.
22	2	32	Chas. Perry		55	6	48		Sand 30 feet; clay to water bed.
22	2	30	P. Mark		38	8	47½	Hard	Water rises 12 feet above surface.
22	2	32	Mr. Cook		26	5			All clay.
22	2	31	Mr. Rice		48	7			

ROSE CITY AREA.

Location.—The flowing wells of the Rose City region are distributed over an area of 3 square miles (fig. 58), which lies to the east of a Saginaw Bay moraine, here 1,200 to 1,500 feet above sea level. The eastern slope of this moraine forms the catchment basin for the

vaters of Rifle River, and the sand plains north and west belong › catchment basin of Au Sable River.

e flowing-well district, of which that at Rose City is a part, extends of north, following the trend of the neighboring portion of the ine, and good flows have been obtained for 3 miles in that direc-

Three miles north of the town the morainal ridges turn to the east, and along this southern slope a few wells have been l, and there is a strong probability that 2 miles north of the vil- of Lupton and Maltby flows could be obtained near the base of ridges. South of Rose City, on the eastern slope of the morainal ry, many strong springs occur, but no flowing wells as yet. ccessful attempts have been made at Campbells Corners on a inent point, which not only seems too high for a flow, but is liable ve its water table lowered by creek-valley drainage on either side.

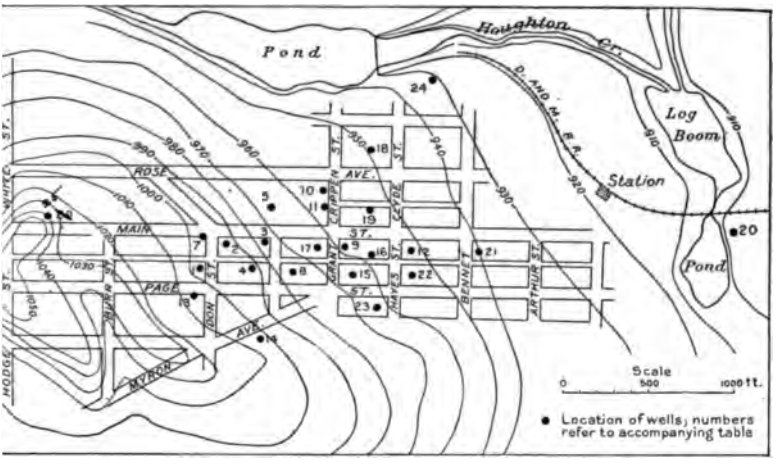


FIG. 58.—Map of Rose City, showing location of flowing wells.

ells.—There are at present 25 flowing wells within the limits of village of Rose City and 8 outside of the village. The first of in Rose City was drilled in 1894, on the property of H. Hodge, in vestern part of town. The 25 wells furnish an abundant supply od water for domestic purposes to the 300 inhabitants. Some of tronger flows, as that belonging to Professor Karcher, are piped pply several families, a small rental being paid to the owner for privilege.

e shallow wells are made by driving a 2-inch galvanized iron pipe, out point or screen, down to the waterbed. These wells are by the job, and $30 to $40 is the average price for the well com- , including pipe and the labor. The stronger flows, which are from leeper of the two beds discussed below, are made by price per which is usually 50 cents, exclusive of piping, making the average

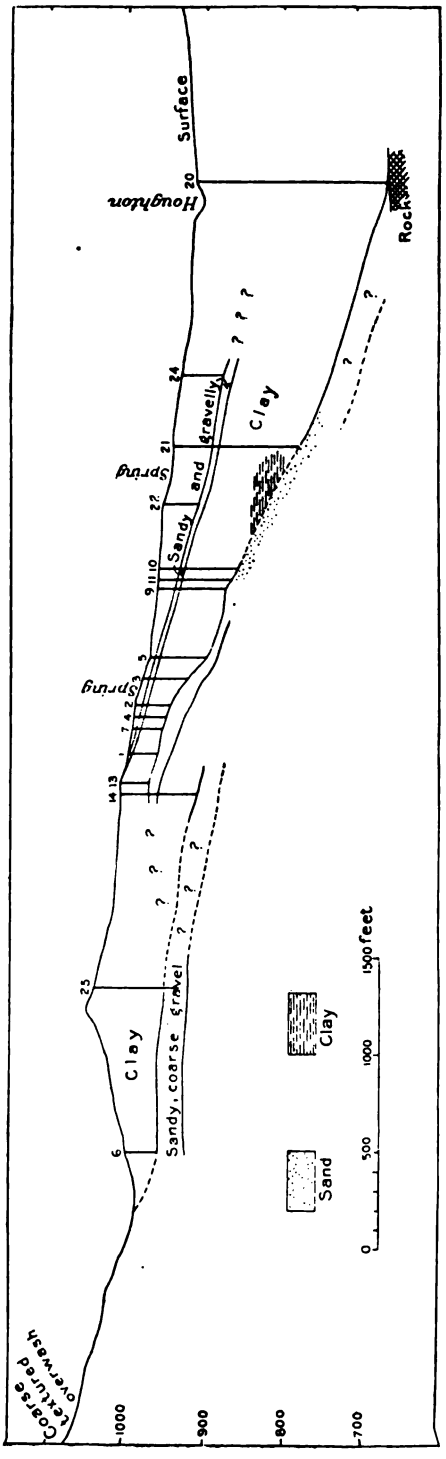


FIG. 59.—Ideal section showing distribution of water beds.

cost of each well from $70 to $80. The wells require very little repairing, but must be sand pumped as often as once in three years. This costs about $10. The average cost of these wells is so low and the quality of the water so good that such a supply is one of the valuable resources of the town and ought to be carefully guarded from unnecessary depletion or waste.

Flow.—The total flow of the Rose City wells amounts to about 2,290 gallons a minute from 20 of the 25 wells which could be measured, which gives over 10,000 gallons daily per capita, or far above the maximum amount used in any city in the State. The individual flow of the wells appears in the table on page 293. With a few exceptions the wells are allowed to flow freely, a practise which, as already suggested, tends to decrease the head. As yet no failure to obtain a flow has resulted where the trial has been made on ground which stands below 990 feet above sea level, and none of the wells have shown a marked decrease in flow since they were first made, except in cases where they have become sand clogged; but in such cases sand pumping restores the original flow. A case in point is that of Doctor Kiehle's well, which had a flow in 1902 of 108 gallons a minute, and some

ıe later was stopped with sand and ceased to flow for several nths, but on being sand-pumped early in 1904 resumed the same v as at the time of the first measurement.

Vater beds.—Two water horizons are usually found in driving these ls. One from a bed of sand quite near the surface, and the other m a gravel bed somewhat irregular in its dip, yet always containing abundant supply of water under considerable head. The first or ɔer bed has been found in nearly all of the wells that have reached lower stronger flow. The relations are set forth in the accompany- diagram (fig. 59), where it will be seen that the thickness of the ɔer bed is from 8 to 10 feet. The supply of water in this upper bed y come, to some extent, from the upward rise of water from the 'er bed, since its outcrop or intake is but a narrow strip not large ıugh to supply the amount of water yielded by some of the wells ,t terminate in this upper bed. Where the upper bed is cut into Houghton Creek, above the mill pond, many large boiling springs ur, and at the time the writer was in this region in 1904 the pond l the creek had a gray color from the breaking out of several new ings that the creek had opened by its recent active cutting on its thern bank.

'he lower water bed, which supplies the stronger flows, contains rse gravel. Some sand occurs in the western part of the town and ms the larger part of the bed in the eastern part. The fact that eral of the wells of the eastern part, although of lower altitude than se of the western, have less velocity of flowage may be due to the 'r texture of the material. This stronger bed appears at an alti- e of 960 feet in the well of Mr. Hodge (No. 6) in the western part of town and dips only slightly to the east until the public-school well eached. This well apparently passed the main bed, as Mrs. Slater a well only a few feet below it giving a good flow and rising nearly feet above the surface, suggesting that the schoolhouse well may 'e been carelessly drilled. From the Slater well the deeper water dips rapidly to the east, being found at 940 feet above sea level in Cooley well, 870 feet in Professor Karcher's well, and 780 feet in Houghton House well.

'he porosity of this lower water bed in the western part of the vil- ' is well shown when the W. Rose well is shut off, for in twenty ıutes afterward there is an increase in the flow of the Cooley well feet to the southwest. This continues to increase for several .rs, until the well has regained its original flow. The lower water is the principal source of supply for the larger wells of the village, the limit of flow apparently has not been approached, as none of wells show any indications of decrease.

'uality of water.—Examination of the quality of the water by field hods shows an entire absence of sulphates and chlorides. The

shallow wells contain a larger amount of carbonates than the deeper ones. The degree of hardness in some of the deeper ones is so low that no softening preparation is used for washing or for laundry purposes. None of the wells have notable deposits of the iron precipitate and the pipes do not corrode rapidly.

Temperature.—The temperature of the wells averages a little below 49° F., which is very suitable for water used for cooling and drinking. The mean annual temperature of Rose City is 6° lower than the average well temperature; but the soil in northern latitudes, where snow prevents radiation for several months of the year, has a greater mean temperature than the air. This probably accounts for much of the difference here between the mean temperature of the air and of the soil. (See pp. 15-20.) The well on the property of the Rose City stave mill shows how the well temperatures are affected by outside heat. This well ought to have a temperature of about 50°, and its temperature of 56° was first noted by Dr. A. C. Lane, and the boilers of the engines given as the cause of the increase.[a]

Catchment area.—Attention was called above to the high morainal ridges west and north of Rose City, which form the boundary of the flowing-well district in those directions. These in all probability constitute a catchment area for much of the water within the flowing-well district. In the portion of the district from which the village obtains its supply a catchment area appears to be found close at hand. The contour map (fig. 58) shows a culminating point in the western part of the town, standing 150 feet above Houghton Creek, a stream which rises in the heavy springs along the eastern slope of the morainal country to the west and which in the eastern part of the town is a small stream of about 50 second-feet volume. West of this high tract in the west part of the village and outside the town is a lower belt of loose-textured material one-eighth mile wide, which lies between the high point in the village and the high land to the west, and which rises in morainal ridges until the crest is reached at an elevation of about 1,500 feet on Cooks Knob, 3 miles west of Rose City. This belt of loose-textured material runs parallel with the large ridges to the west, having the same general north-south trend, and seems a probable catchment area intimately related to the Rose City wells. The loose-textured material apparently dips beneath the ridge in the west part of town and is covered by several layers of clay, which are impervious enough to retain the water and give it considerable head in places of lower elevation. This catchment area is probably itself fed by the high ridges to the west of it, just as Houghton Creek is fed from a portion of the ridges farther north.

[a] Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, p. 57.

Wells at Rose City.

	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*	° *F.*			
1	Mrs. Slater	998	2	43	960	1,012	109	48	Medium.	$30	House use.
2	Dr. Kiehle	990	2	46	944	.....	108	48	Soft	.....	Do.
3	W. Rose	978	2	60	918	996	221.7	49	....do...	67	House well; interferes with No. 4.
4	J. Cooley	990	2	45	945	.....	30+	48	....do....	50	Supplies 5 families; total flowage not measured.
5	H. Rose	968	2	76	{960 {905	988	28	48	....do...	35	House use.
6	H. Hodge	1,000	2	40	962	.....	110	48	....do...	50	Pioneer well, made in 1894.
7	O. Morrison	994	2	41	953	.....	42	48	....do...	38	House use.
8	E. Atherton	976	2	100	.....	.....	150	49	....do...	78	Supplies 4 families.
9	Wm. Tulloch	958	2	90	868	987	225	49	....do...	75	Supplies 5 families.
0	A. S. Rose	957	2	100	860	969	272	49	....do...	80	Supplies 10 families
1	Prof. Karcher	957	2	95	865	969	270	48½	....do...	75	Supplies 15 families.
2	M. Lansbury	953	1½	00	.....	.....	.....	.....	.....	.....	
3	E. Rennier	1,006	1½	35	972	1,007	5	....	Medium.	.....	House use.
4	Public school	1,007	2	100	{974 {907	.....	.....	.....	.....	125	No flow.
5	C. Clearmont	965	2	60	.....	.....	15	.....	.....	.....	Clogged with sand.
6	D. Warner	958	1½	120	.....	.....	.....	49	.....	80	House use.
7	H. Beach	964	2	100	.....	.....	120	.....	Soft	.....	Do.
8	A. Rose	950	2	120	.....	.....	60	49	....do...	84	
9	J. Machny	954	2	107	.....	.....	135	.....	.....	.....	Do.
0	Stave mill	910	1½	241	677	915	.....	56	Hard.	.....	Soft sandstone at 233 feet.
1	Houghton Hotel.	940	2	160	780	980+	150	50	Soft	90	Used in hotel laundry.
2	Wm. Tulloch	952	2	42	910	.....	100	48	.....	.....	House use.
3	....do	962	2	138	.....	.....	40	49	Soft	110	Supplies 8 families.
4	A. Rose (mill)	930	2	50	.....	.....	28	48½	....do...	28	Used in boiler.
5	A. Cary	1,040	2	120	{990 {920	990	00	....	.....	.....	On brow of hill.

WATER SUPPLIES OF MANISTEE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Manistee County fronts on Lake Michigan in the western part of he Southern Peninsula, the city of Manistee being the county seat. Ianistee River traverses the southern part of the county, and with s tributaries drains all of the county except a narrow strip on the orthern and western borders. The district south of Manistee River largely a sandy plain, and has few settlers except at the village of ublin, outside the city of Manistee and its suburbs. North and est of Manistee River in the east is a prominent morainic system, large part of which has become settled. The wells on it range in epth from 50 feet or less up to fully 200 feet. West of this morainic stem there is a broad, sandy plain traversed by Bear Creek, a tributry of the Manistee, in which a strong flowing well has been obtained. ne northwestern part of the county west of Bear Creek and north Manistee River is largely morainic, but has recesses extending in om Lake Michigan in which flowing wells have been obtained. One ıportant district on the borders of Portage Lake, in and near the

village of Onekama, is discussed by Mr. Gregory (pp. 297-301). There is a smaller district near Arcadia, concerning which a few data are presented below. The wells on the moraines in the northwestern portion of the county are often driven to depths of 75 to 100 feet, though as a rule the hills are avoided and wells are sunk in depressions, where water is found at convenient depths.

The salt wells at Manistee penetrate about to sea level before striking rock, but at Onekama rock is reached at a level 100 feet or more above tide. It is not known whether the altitude of the rock surface continues low to the eastward across this county, for no other borings have been driven to the rock. The highest points in the eastern part of the county have an altitude of more than 1,000 feet above sea level. If, therefore, the rock surface does not rise in that part of the county, there would be about 1,000 feet of drift. Borings at Manistee and Onekama, as well as the shallower ones elsewhere in the county, show the drift to be largely gravel and sand, which is filled with water below the level of the streams, but which is liable to be dry at points much higher than the drainage lines.

WATERWORKS.

MANISTEE CITY.

The city of Manistee, with a population of about 14,000, stands on the shore of Lake Michigan at the mouth of Manistee River. It is supplied from a system of wells sunk on a terrace a short distance from the lake, on the south bank of Manistee River. There is a large excavated well, 30 feet in diameter and 40 feet deep, with which are connected three 8-inch wells which extend 60 feet below the level of the bottom of the large well and about 75 feet below the river and Lake Michigan level. The large well was excavated in sand, though there was a bowldery bed at 23 feet and an occasional streak of gravel. The tubular wells are through sand, except for 10 feet of brick clay near the bottom. The water stands 23 feet below the surface, or at about Lake Michigan level. The following analysis of water was made by Ricketts & Banks, of New York City, July 25, 1899, just before the purchase of the waterworks by the city:

Analysis of waterworks water, Manistee.

	Parts per million.
Chlorine (Cl)	5.33
Sodium (Na)	3.47
Nitrogen in nitrites	.02
Nitrogen in nitrates	5
Free ammonia	.08
Albuminoid ammonia	.07
Calcium (Ca)	74.84
Carbonic acid (CO_3)	112.06
Loss on ignition	35

Analysis of waterworks water, Manistee—Continued.

	Parts per million.
eral matter, nonvolatile	157
al solids (by evaporation)	192
ı (Fe)	None.
ıe	72
gnesium (Mg)	14.50

ppearance, clear; color, none; odor, none.

The works were acquired by the city October 1, 1899, from a private ıter company, the price paid being $125,155.81. The extensions ıde since purchasing the works have brought the cost up to 60,394.10, as shown by the annual report for the year ending Febary 28, 1905. The length of mains is now 21.33 miles. There are 7 fire hydrants, 1,540 service taps, and 98 meters. The ordinary essure carried is 63 pounds, and fire pressure 100 to 120 pounds. ıe water is pumped direct to the mains.

The average daily consumption of water is 819,344 gallons. This a lower rate than prevailed when the works were acquired by the y, although the number of consumers has increased 25 per cent. tendency to guard against waste is therefore developing in the mmunity. Superintendent Stephen Cahill, who furnished the data ncerning this waterworks system, estimates that about 60 per cent the population, or 8,500 people, are now using the city supply. ıe remainder depend on private wells, which range in depth from to 90 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

At Arcadia the supply is from driven wells 20 to 25 feet deep, ıich strike water at about the level of Lake Michigan.

At Chief the wells are commonly about 50 feet, but wells in the untry around reach depths of 150 feet, and when on high points ve only 10 to 20 feet of water.

At Onekama the flowing wells, ranging in depth from 40 to 300 feet, in general use and have a pressure equal to a head of about 70 t and a discharge as high as 168 gallons a minute from a 2-inch ɔe. These wells are discussed in some detail by Mr. Gregory p. 297–301). There are a few pump wells on the hill back of the lage ranging from 10 to 100 feet in depth. Springs in the vicinity the village are strong and yield as high as 50 gallons a minute.

At Pierport, on the shore of Lake Michigan, wells are from 10 to 5 feet in depth, though they are commonly less than 60 feet.

At Tanner, in the valley of Bear Creek, wells are commonly about feet deep, though tubular wells reach a depth of 80 feet.

At Brethren, on the plain east of Bear Creek, and also at Kaleva, lls are driven to depths of 20 to 30 feet and find abundance of *ter.*

At Copemish the wells are but 15 to 30 feet in depth, though in the higher country immediately east they are much deeper.

At Harlan, in the northeastern part of the county, there are a few shallow open wells, but the driven wells in that vicinity are usually 100 feet or more in depth.

At Dublin, in the southeastern part of the county, the wells are 70 to 75 feet in depth and have very little head, but at Wellston siding, 3 miles north, an abundance of water is found at 16 feet.

FLOWING WELLS.

ARCADIA.

There are two flowing wells east of the village of Arcadia, in northern Manistee County, on a low plain bordering Lake Michigan—one on the farm of Luther Finch, the other at a German cemetery. The Finch well, in sec. 11, T. 24 N., R. 16 W., is about 1 mile from the lake and 40 feet above it. It was made in April, 1903. The cemetery well is a mile farther east, on somewhat higher ground, and has been running for about four years. (See Pl. V, *B*.) The Finch well is 187 feet deep and flows a half-inch stream from a 3-inch pipe. It has the following section, as reported by the owner:

Record of Finch well, east of Arcadia.

	Thickness.	Total.
	Feet.	*Feet.*
Red sand, lake deposit	4	4
Red glacial clay (till)	80	84
Water vein with head of −2 feet		
White sand	80	164
Light-colored clay	10	174
Clay and gravel	3	177
Water gravel with head of 14 feet	10	187

The cemetery well is 143 feet deep and flows a 1-inch stream, which has shown no perceptible diminution in the four years it has been flowing.

The catchment area for these wells is likely to be in the bordering morainic hills which sweep around the plain on which they occur on the north, east, and south. It is probable that other wells may be obtained on this plain if sunk to levels as low as those already obtained. In most cases wells are shallow and afford sufficient supplies by pumping. There are numerous springs along the base of the morainic tracts bordering this plain, which are utilized by the residents.

VICINITY OF KALEVA.

Andrew Kullgren has a flowing well on the bank of Bear Creek, about 4 miles northwest of Kaleva, with a depth of 130 feet. At about 30 feet he reached the bottom of the surface deposit of gravel and sand and penetrated clay to the water-bearing gravel at bottom.

Joseph Gilson has a flowing well in a recess of a moraine about miles east of Kaleva, in sec. 20, Marilla Township, with a depth 75 feet and a head of 2 feet. Water was struck at 65 feet, with temperature of 45° F.

Joel Gilson has a well in the same region, made in March, 1903; pth 75 feet, diameter 2 inches, with a head of 2 feet. Water was ruck at 70 feet and is soft. The well is located in a stream bed.[a]

BEAR LAKE.

A newspaper report concerning a flowing well at Bear Lake ppeared in the Jackson (Mich.) Press October 26, 1904, as follows:

Manistee, Mich., October 26.—A farmer living near Bear Lake has an artesian well on is farm which spouts both water and gas. The well in 419 feet deep and the pipe is rked at the surface and one part, which is considerably higher than the other, emits as, while water flows from the lower one. The farmer intends storing the gas in a tank nd will use it to light his home this winter.

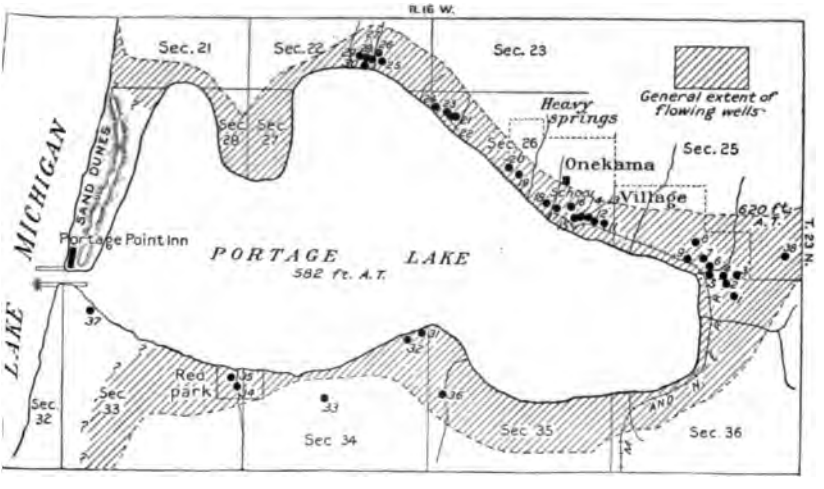


FIG. 60.—Flowing wells in and near Onekama, Manistee County.

ONEKAMA.[b]

The Onekama district is a narrow strip of land about Portage ake, in Manistee County, having an elevation of 582 to 620 feet ove tide. The lake is surrounded by high hills of porous drift eposited in part by a small local ice lobe. At the west end of ortage Lake currents in Lake Michigan have built a bar and piled e sand in dunes, so that the once wide mouth of this basin is early closed. The Lake Michigan shore north of this region has a)-foot cliff of clay capped with varying depths of sand and gravel.

[a] Data by A. L. Gleason, driller.

[b] By W. M. Gregory.

The high hills of 200 to 300 feet above the lake average a mile back from the shore of Portage Lake.

The Onekama district has at present 40 wells, 36 of which are good flows and the remainder either failures or very weak (fig. 60). The wells are all drilled, nine being driven, as the clay is compact and the sand is often consolidated. The tubular-well machine with a water jet is generally used for sinking wells in this region. In the shallow wells and in drift which is less compact and tenacious an outfit of similar construction is utilized. The wells are generally made by contract, varying from 75 cents to $1 a foot in the deeper wells, and by the job for a flow in shallow wells. Some few of the wells require a screen, but generally the supply is from a rather coarse gravel water bed. The wells are in general use throughout the district for domestic purposes, dairy and stock use, and water has been occasionally shipped from Mr. Canfield's well to outside markets.

The waters are soft enough for all domestic purposes and are preferred by some to the lake water for laundry purposes. The field analyses show that the hardness is above the average of the drift water, while the carbonates are low, and the chlorides are above the normal water.

The combined flow of the 36 wells is 2,197 gallons a minute, or 61 gallons a well, which is a high rate. Changes in flowage of several wells occurred when Mr. C. J. Canfield's well (No. 23) was made. This well has an estimated flowage of 250 gallons a minute.

The deposits of this region consist of alternate clay and sand layers, and the latter form many water beds which give flows of varying strength, depending on the coarseness of the material. The alternating character of these beds is shown in the record of John Neitzke's well (No. 3), where a small flow was found under each clay bed. At the western end of the lake no flows are obtained, a few trials showing this to be a sand bar built across the mouth of the lake. At the fish hatchery the most productive bed is the third one, at 43 feet, though porous gravel beds have been found at 19 feet and at 25 to 35 feet, while a small flow comes from the Antrim shale, which is reached at 425 feet. At Mr. Canfield's, one-half mile east of the fish hatchery, there is a coarse gravel water bed, at 160 to 170 feet, which yields a heavy flow. This bed apparently rises to the east. In Mr. W. W. Davis's well (No. 14) it is found at 160 feet; at A. E. Solomon's (No. 12), at 157 feet; and at the cheese factory (No. 5), at 138 feet. Below this bed there are several others ranging from 224 feet in the well of W. W. Davis (No. 14) to 300 feet in A. L. Showalter's (No. 6).

The deposits on the south side of the lake are more sandy than those to the north, and the wells have not been so successfully developed. A fairly good supply is obtained at less than 100 feet by

Noud (No. 34), Joe Frisbe (No. 35), and H. Hanson (No. 36). Sev-
l of the wells which have been drilled to the Antrim shale at 472
t yield no water. Mr. August Lipkowski (No. 33) obtains gas
ugh for two burners from a well in this shale.

The catchment area of wells about Portage Lake is in the high-
ds of Glacial drift which reach an elevation of over 900 feet above
e about the border of the lake. Well drillers find it difficult to
tain water on the high hills, for wells have much loose, porous ma-
ial and few seams of clay. The general absence of creeks north
d south of this area is the result of the porous character of the
ft. When the clay comes to the surface at lower elevations lakes
springs are the result. The upper limit of strong springs along
rtage Lake is at 650 feet above tide, and some are well developed
620 feet. Some springs in the western part of Onekama village
ve recently burst out in new places. The supply for the fish hatch-
y well (No. 27) is evidently drawn from the water bed that sup-
es the small creek which heads in several springs at an altitude of
5 feet above tide.

The area affords some good data concerning the well pressure
ich it has not been possible to obtain from other regions. Mr.
W. Davis, a competent well driller, has taken much interest in the
ssure of the different wells, and has arranged to measure it in each
means of a small steam boiler fitted with a gage. The pressures
e all been carefully recorded in the accompanying table. The
atest pressure is 35 pounds to the square inch, which is reported
Mr. Davis from wells No. 21, 22, and 23, and seems rather large.
e writer saw Mr. Davis test well No. 25 with the apparatus which
been used on the other wells of the region. The pressure gage
istered 20 pounds to the square inch, or 5 pounds less than when
well was first made. Mr. Davis asserts that this decrease is due
sand in the pipe.

Wells at Onekama.

No. on fig. 60.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Gage pressure.[a]	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	° *F.*			*Lbs.*	
1	J. E. Carleton[b]	607	2	185	422	656	75	49½	Soft	$75	30	Domestic use
2	J. E. Carleton	602	2	132	471	647	75				20	Barn and pasture.
3	John Neitzke[bc]	610	2	290	320	667	150		Medium		25	Domestic use.
4	Henry Smith	602	2	129	473	659	102	49	Soft		25	House and barn.
5	Cheese factory	597	2	138	359		50				10	Cooling room.
6	A. T. Showalter	597	2	300	297	642	150		Medium	208	20	Domestic use.
7	H. Hanson	597	2	101	496	633	125	49	Soft		15	Do.
8	O. Peterson	597	2	85	512	633	125	49			15	Do.
9	J. J. Kenny	594	2	291	303		100	49	Soft		10	
10	R. F. Wendell[b]	592	2	83	509		100			83	10	
11	A. F. Richmond	594	2	128	468	649	140	49	Soft		20	
12	A. E. Solomon[d]	602	2	157	445		100	49½		150	8	Hotel.
13	J. E. Erickson	607	2	159	448		100				8	
14	W. W Davis[e]	607	2	244	363		150	49½			25	First flow at 160 feet.
15	Wm. Hoglin[b]	607	1½	40	567	622	40				6	Domestic use.
16	Fred Brown	612	2	134	778		160	49	Soft		32	House and barn.
17	Chas. Tomlin	597	2	157	420		125	49	do		15	Piped to second story.
18	F. Hall	597	2	40	557		75	49½	do		8	All clay; flow in gravel.
19	Mr. Miniter[b]	607	2	85	522		125				20	Piped to second story.
20	Ramsell & Marsh	604	2	67	547		75	48½	Soft		11	
21	C. J. Canfield	607	2	162	445		168	49		160	35	Water from gravel.
22	do	607	2	168	439		168				35	
23	C. J. Canfield[f]	607	3½	162	435		250		Soft		35	Occasionally sold for drinking.
24	C. J. Canfield	607	2	126	481		74			120		
25	Fish hatchery	602	2	43	559		75	48½				
26	Fish hatchery[g]	602	2	425	177		10		Hard			Rock at 300 feet.
27	Fish hatchery	602	1½	19	583		30					
28	do	602	2	25	577		30					
29	do	602	2	35	567		35					
30	do	602	2	304	298							No water.
31	E. L. Reeves[h]	592		304	288		100		Hard		25	Water from gravel.

[a] W. W. Davis, a well driller of Onekama, is authority for the pressures, which were obtained by connecting well to boiler with steam gage attached.
[b] Screen used only in Nos. 1, 3, 10, 15, 19, and 38.
[c] The following is the record of this well:

	Thickness.	Total.
	Feet.	*Feet.*
Sand	18	18
Clay	99	117
Sand	12	129
Clay	24	153
Sand	32	185
Clay	24	209
Sand	23	232
Clay	45	277
Gravel and sand; water bed	23	300

[d] A field analysis of the hotel well is as follows:

	Parts per million.
Hardness	187.6
Carbonates	24
Chlorides	15
Iron	0

[e] A field analysis of water from the Davis well is as follows:

	Parts per million.
Hardness	175.5
Carbonates	29
Chlorides	15

Wood was found in this well at 110 feet.
[f] When well No. 23 was drilled, 100 feet west of No. 21, the pressure in the latter was decreased from 35 to 28 pounds. Wells Nos. 22 and 23 are connected, and the total flow is used to operate a water turbine which gives power for a small electric-light plant.
[g] Strong pressure of gas, which rapidly decreased.
[h] Beneath 96 feet of surface sand and 16 feet of marl and clay are alternating beds of clay and sandy gravel, the clay predominating.

Wells at Onekama—Continued.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Gage pressure.	Remarks.
	Ft.	*In*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			*Lbs.*	
'm. Nuttall[a]	592	....	225	367	.....	100	....	.....	175	15	
ug. Lipkowski[b]	642	2	418	224	646	.....	....	Hard	.....	....	
'at. Noud	.....	....	83	.....	+11	20	....	Soft	.....	....	Stock and domestic use.
oe Fiske	.....	2	65	.....	+17	75	....	.....	50	....	Passed 6 water beds.
Ians Hanson	612	2	63	549	.....	20	....	.....	.....	10	
.. Clark estate[c]	592	2	472	120	.. .	.....	....	Hard	.....	....	No water.
:d. Kinney[d]	594	1½	43	551	.. .	25	....	.....	.....	5	Some gas at intervals.
Ir. Klein	.....	2	225	.....	+32	5	....	Soft	160	....	Sand 13 feet; remainder tough clay.
'ublic school	624	2	40	.....	616	.....	....	.....	.....	....	

nd 103 feet; remainder soft clay, with some sand and gravel.
s enough to supply two burners in one house for the past year.
cord of well, with 100 feet unaccounted for:

	Thickness.	Total depth.
	Feet.	*Feet.*
.....	128	128
.....	14	142
.....	20	162
.....	30	192
sh shale (?)	123	315
shale	57	372

een used only in Nos. 1, 3, 10, 15, 19, and 38.

WATER SUPPLIES OF WEXFORD COUNTY.

By Frank Leverett.

'exford County, of which Cadillac is the county seat, is immeely east of Manistee County, in the western part of the southern nsula. Its southeast corner is between the Lake Michigan and naw lobes, on a prominent interlobate moraine, the highest point 'hich rises to a little above 1,500 feet and the greater part of ;h is above 1,300 feet. In this moraine wells have in several s reached depths of over 200 feet before striking water, though high hills are generally avoided and water is reached at 100 feet ;ss. This moraine extends but little north of Cadillac. Along orthwest border is a sandy plain several miles wide in which the ı lakes are situated, from one of which the waterworks supply of llac is drawn. North and west of this plain is a prominent aine, with a crest 1,400 to 1,500 feet above tide. The village of ne is near its eastern border, and Harrietta is in a recess on its ern border, while Sherman and Manton are also near the inner ler. It is a tract in which the few wells made are ordinarily deep, much of it is still unsettled. West and north of this moraine is oad plain through which Manistee River flows. It is largely cov- with sand, but portions of it between Manton and Sherman have

till at surface. The part north of the river is an outwash from a moraine that runs through eastern Manistee and southern Grand Traverse County. On this plain water is usually found at depths of 20 to 50 feet, or in harmony with the streams flowing into Manistee River. The county is tributary to Manistee River except a few square miles in the southeastern part that drain eastward through Clam River to the Muskegon.

Throughout the county the drift is so loose textured that water is nearly all absorbed, and there seems to be a general water table in harmony with the streams. Wells on high points and elevated plains generally go about to the level of the neighboring streams to strike water, and this in the highest ridges is about 200 feet. So far as known there are no flowing wells in this county. The only places where they seem likely to be found are in recesses in the moraine south of Manistee River, or along the low bottoms of the river or its tributaries.

No borings have been carried to sufficient depth in this county to reach rock, and it is probable that the rock lies several hundred feet below the surface.

The city of Cadillac and the village of Manton have waterworks plants using surface water. That of Cadillac is from Little Clam Lake which lies west of the city. The Manton supply is from a small stream running through the village. Wells are in common use for drinking at both towns. In Cadillac wells which the public utilize have been drilled along some of the streets in the business section. Analyses of water from the lake and from private wells at Cadillac were made by Mr. Lewis, who found that some carelessness is displayed in selecting the sites for wells. The porous character of the soil in this region is such that it will readily receive whatever surface contamination there may be.

In the accompanying table are given the results of a number of partial analyses made by S. J. Lewis in the vicinity of Cadillac. The lake water is soft and satisfactory. The Platt and Leeson wells are both supplied from sand beds in the drift. The Leeson water shows the normal composition, but the high percentage of chlorine in the Platt water indicates that it may be polluted by seepage from the near-by barns of the owner. The data are furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well and lake waters at Cadillac.

[Parts per million.]

	1.	2.	3.
›r	46	65	37
n (Fe)	Strong trace.	.5	1
orine (Cl)	21.7	51	24.25
bon dioxide (CO_2)	20.05	78.09	80.14
phur trioxide (SO_3)	0	36	0
rdness (as $CaCO_3$)	90.6	139+	139+

. J. Lewis, analyst. 1. Lake. 2. J. H. Platt; depth, 36 feet. 3. Dr. J. Leeson; depth, 113 feet.

The data on village supplies given below were largely obtained by rrespondence:

Village supplies in Wexford County.

Town.	Elevation.	Source.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
nson post-office.	1,300±	Springs and driven wells.	16	200	40	150	−20	Small.
one	1,387	Driven wells	104	246	104	104	.....	
dillac	1,280 1,400	Driven wells, and waterworks supply from lake.	30	150	50	50	.....	Do.
lbert	1,250±	Driven wells	15	135	50	50	.....	None.
rrietta	1,115	.....do	35	.....	35	.....	.....	Large.
bart	1,300	.....do	50	200	.....	.....	.....	Small.
nton	1,132	Spring brook for waterworks and wells.	12	30	.....	30	−12	Large.
erman	920	Open and driven wells	10	90	25	25	.....	Small.
exford	1,000±	Driven wells	35	185	50	60	−40	
ima	982	.....do	15	150	20	20	−15	

WATER SUPPLIES OF MISSAUKEE COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Missaukee County is situated east of Wexford County, and is ·ossed by the same morainic systems as the latter, the interlobate ıoraine being in the southwest corner and the strong moraine north f it running through the center in a course south of east. There is large amount of till plain between the two moraines in the south nd also a till plain in the east. On these till plains the water table generally near the surface, portions of them being swampy; but the ıoraines are of gravelly constitution and the water table is near the ›vel of their bases or but little higher than in the till plains. The ıoraines have reliefs of 50 to 100 feet or more and the wells along hem are of corresponding depths. In the northeast there is coniderable swamp underlain with sand; this is unsettled, but there are ettlements on its northwestern border at Stratford and Moorestown. North of this swamp, along the border of Kalkaska County, is a norainic belt which crosses to the north side of Manistee River near

the northwest corner of the county. This morainic belt also is largely unsettled.

The greater part of the county drains southeastward into Muskegon River, but the northwestern part is tributary to Manistee River. In the western part, near Jennings and Lake City, there is a group of lakes, one of which is drawn on for the water supplies of those towns.

FLOWING WELLS.

In this district are three flowing wells, one at and two near Dolph post-office, in the Muskegon Valley, in the eastern part of the county.

DOLPH DISTRICT.

The well at Dolph is owned by F. L. Witherell, and has a depth of 62 feet. It stands on ground about 8 feet above Muskegon River, and has a head of 8 feet and a flow of about 9 gallons a minute. It penetrated blue clay and "putty sand" to the flow at 36 feet. The well was continued to greater depth in order to strike gravel, but found only fine sand in the lower portion.

A short distance north of Dolph, in sec. 34, Butterfield Township, also in the Muskegon Valley, is the flowing well of Elisha Clifford, about 40 feet in depth.

Another flowing well was made by a Mr. Bowman on a tributary of Muskegon River northeast of Dolph, in the edge of Roscommon County, but this was not visited.

McBAIN DISTRICT.

East of McBain, in sec. 21, Riverside Township, is the flowing well of John Gates, 34 feet in depth, with a head of at least 2 feet. It struck water at 4 feet and found it all the way down. The well cost $12.

There is a flowing well at D. G. Spreksell's, 1½ miles east and 1 mile south of McBain, about 25 feet in depth.

William De Zwaan has a flowing well about 40 feet deep located 3 miles east and one-half mile north of McBain.

There is also reported to be a flow, made by some hunters or campers, in an unsettled tract near the edge of Osceola County, southeast of McBain.

The extent of this district and the number of flows can probably be greatly increased, for the high moraine to the west forms a good catchment area. The flows near Dolph also lie east of a strong moraine, and it is probable that this district may be extended along Muskegon River and its tributaries. Much of that country is unsettled, so there has been no demand for wells.

WATERWORKS.

LAKE CITY.

The waterworks plant at Lake City is owned by a private company, d water is pumped from Lake Missaukee. It is largely used for inking as well as for fire and sprinkling. It is soft enough for ındry use and in boilers. Some residents consider this supply less tisfactory for drinking than wells.

JENNINGS.

The waterworks at Jennings are operated by a private company, ıd the supply is drawn from Lake Missaukee. The water is soft ıough for boiler and laundry use. Wells are in common use for rinking, as there is some distrust of the safety of the lake waters. 'he wells are usually 60 to 80 feet deep.

MISCELLANEOUS VILLAGE SUPPLIES.

Village Supplies in Missaukee County.

Town.	Population.	Elevation.	Source.	Depth of wells. From—	To—	Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
utterfield			Driven wells	14	116	14-35	27	−22	Large.
ennings	900±	1,275±	Driven wells, lake	20	80	60	60	.....	Small.
ake City	816	1,260±	Driven wells, Missaukee Lake.	15	60	30	60	.....	Do.
ucas	200±	1,299	Driven wells	25	40	40	40	−30	None.
cBain	709	1,232	do	43	185	80	80	−20	Small.
ioneer			Open and driven wells.	20	190	50	50	−20 −40	Do.
ittsville			do	16	100	25	100	.....	Do.
tratford			Driven wells	25	.....	25	.....	−18	Do.

WATER SUPPLIES OF ROSCOMMON COUNTY.

By Frank Leverett.

General statement.—Roscommon County is situated east of Misaukee County, and embraces a high table-land in which Muskegon iver and south branch of Au Sable River have their sources. The ead of the Muskegon is in Higgins Lake, which lies at an altitude of bout 1,150 feet and embraces an area of several square miles, borered on the north by a moraine which rises above 1,200 feet. The utlet leads into Houghton Lake, a body of water about 10 miles long ıd 4 miles wide, whose altitude is about 1,125 feet. In the southıstern part of the county is a prominent moraine of the Saginaw lobe hose highest points are fully 1,400 feet above tide. On the borders f Houghton Lake and eastward across the county to Lake St. Helen re extensive swamps, underlain in large part by clay. Between this vampy tract and the high moraine in the southeast are extensive

sand plains, parts of which are being developed as a forest reserve. On these sand plains the distance to water is but a few feet, and basins in them are occupied by swamps and small lakes. There are several small groups of hills scattered over the county, which, being composed largely of gravel and sand, probably have a water table at considerable depths. The water table also is at considerable depth in the high moraine in the southeast.

The county is very sparsely settled, the population in 1900 being but 1,787, of whom 465 were in Roscommon village. Most of the farming is done in Richfield and Markey townships.

Flowing wells.—At the west end of Houghton Lake there is a well about 30 feet deep, which flows at a level 8 feet above Muskegon River, on the bank of which it stands. It is largely through blue till.

Another flowing well, noted in the Missaukee County discussion (p. 304), is a few miles southwest of Houghton Lake, on the farm of Mr. Bowman.

So far as known these are the only flowing wells in the county, but it is probable that others might be had from Houghton Lake southwestward into Missaukee County in the swamp traversed by Muskegon River. Whether flowing wells could be obtained on Au Sable River has not been determined. The stream, however, follows the base of a prominent ridge near Roscommon, which may furnish head for flows.

In the vicinity of Houghton Lake, on the Hall farm and at King's store, wells on ground 25 feet above the lake have been sunk to depths of 50 to 75 feet. At Prudenville, a little farther east, the wells are only 12 to 24 feet in depth, and at St. Helen, on the border of Lake St. Helen, they are only 8 to 10 feet. At Nolan lumber camp, on the south side of the prominent moraine in the southeastern part of the county, wells are 8 to 30 feet in depth, and in the vicinity there are large springs. The wells in the neighborhood of Herbert post-office are 14 to 40 feet in depth.

Waterworks.—The village of Roscommon has a small waterworks system in which a windmill pumps water from a spring brook to an elevated tank about 16 by 22 feet, from which water is distributed through about 2 miles of mains to all parts of the village.

WATER SUPPLIES OF ALCONA COUNTY.

By Frank Leverett.

General statement.—Alcona County fronts on Lake Huron north of Saginaw Bay, Harrisville being the county seat. It is more elevated than counties to the north and south, there being a belt of high country fronting on the lake above Harrisville, which extends westward across the northern part. The highest points in the northwestern part reach about 1,200 feet above tide, and there are probably 40

re miles in the western part that stand above 1,000 feet. About
e-fourths of the county stands between 700 and 900 feet above
sea. The lowland bordering the lake is limited to a strip about
iles wide at the south border and 3 miles at the north border,
ch is narrowed to less than 1 mile in the middle part of the county.
he drainage is nearly equally divided between the Thunder Bay
er and Au Sable River systems, the north half being drained
hward to Thunder Bay River and the south half southward and
ward to Au Sable River. A narrow strip on the border of Lake
on is drained by Black River and other small direct tributaries to
lake. Au Sable River crosses the southwest corner of the county
deep and broad valley, but receives no important tributaries in
; part of its course. Pine River, with its numerous tributaries,
ns six townships in the southeast and enters the Au Sable in Iosco
nty. The principal tributaries of Thunder Bay River in Alcona
nty are Hubbard Lake, with its main affluents, Sucker Creek, and
obard Creek in the northeastern part, and Wolf, McGinn, Silver,
Wildcat creeks in the northwestern part. Hubbard Lake is a
y of water 7 miles in length and nearly 2 miles in average width,
dered on all sides by ranges of hills. There are numerous other
es scattered over the county.

t is only in the eastern portion of the county that wells are suffi-
ntly numerous to test the supply of underground water, and even
re only to slight depths. In the thinly settled central and western
tions springs and surface water are generally adequate to the needs
the residents, and the few wells made are usually between 15 and
feet in depth. In the eastern portion wells that are sunk beyond
surface water veins vary greatly in depth and in strength, because
the differences in texture of the drift. They indicate that a wide-
ead bed of sand occurs under the surface clay in the eastern part of
county, which is often dry for a few feet but is charged with water
her down. In such wells there is litt e rise of the water above the
el at which it is struck.

Flowing wells.—It is probable that flowing wells may be obtained
everal localities within the county by sinking to a depth of 100 to
feet or less, for the situation is very similar to that in the flowing-
l districts to the southwest at Rose City and West Branch, in
maw County. One favorable belt is on the eastern slope of a
aine leading from Lott northward across tps. 25, 26, and 27 N.,
5 E. Flows may perhaps be obtained in the southeastern part of
27 N., R. 5 E., and northwestward past McCollum Lake. If the
sheet pushed up into that region from the northeast, as seems prob-
e, the waters that soak in along the elevated moraine that consti-
es the divide between Au Sable and Thunder Bay rivers are likely
e working down the slopes in the direction of surface drainage, and

may have sufficient head to overflow in the comparatively low tracts near the head of Wolf, Silver, and McGinn creeks, and possibly for some distance down these streams.

In the eastern part of the county flowing-well prospects seem good along the lake shore, and flows may also be struck in low ground at the headwaters of tributaries of Hubbard Lake and of the east and west branches of Pine River. One flowing well has already been obtained near a branch of Pine River in sec. 11, T. 26 N., R. 8 E., at the moderate depth of 65 feet, which is at least an encouragement to prospect for others in similar situations along each side of this divide. The well referred to is on the land of Frank Blong, 2 miles southwest of Lincoln. It penetrated clay 18 feet, gravel (with weak water vein) 8 inches, clay with hard crust at about 30 to 35 feet from the surface and softer clay below at 44 feet, and terminated in gravel which yielded a flow of water. The altitude is about 120 feet above Lake Huron, or 700 feet above tide.

Springs.—Large springs abound along the lake front from near Greenbush northward past Springport and Harrisville, which supply the needs of residents to such an extent that but few wells have been made. Springs also abound along the headwaters of the several branches of Pine River and on nearly every stream tributary to Thunder Bay River. The water seeps out in such abundance that most of the streams are bordered by marshy tracts.

Miscellaneous village supplies.—At Harrisville springs issuing along the border of the lake have furnished most of the residents with water. In the winter of 1903 and 1904 a boring was made to test for oil and gas and flowing water. It was, however, located on the court-house grounds at an altitude 60 feet above the lake and a flow was not obtained. Before reaching a depth of 40 feet the well struck two strong veins of water, estimated to supply 150,000 gallons a day from an 8-inch pipe. Another supply was found at 100 to 130 feet in sand below hardpan, and still another was found in the Berea sandstone at 230 to 260 feet. The boring was carried to a depth of 506 feet and has the following section, furnished by J. H. Killmaster, of Harrisville

Record of Harrisville well.

	Thickness.	Total.
	Feet.	*Feet.*
Yellow loamy soil	12.5	12.5
Quicksand, full of fresh water	14	26.5
Red clay	6.5	33
Coarse gravel, full of fresh water	6	39
Bowlder y till	60	99
Sand with signs of oil and fair yield of water	30	129
Red clayey hardpan, with some sand and gravel	59	188
Red clay	4	192
Blue hardpan, with fragments of Berea sandstone	38	230
Berea sandstone, of light color, fine grained	30	260
Light-gray shale	149	409
Brown and black shale	97	506

At Black River village water is hauled from the lake and delivered barrels to the residents, the lake water being of better quality than ıat obtained in shallow wells.

At Greenbush wells 25 to 30 feet deep furnish a good quality of ater and are largely through sand and gravel.

At Lincoln lakes are used to a great extent for watering stock, but he houses are supplied by wells 30 to 40 feet in depth.

In and near Mikado wells are about 30 feet in depth, largely through lay. Farm wells in the vicinity of the village have been sunk to lepths of 60 or 70 feet.

At Killmaster there is abundance of water at various depths, as hown by three deep borings made in prospecting for oil. Fresh ater overflows from the base of the drift at depths of about 240 feet, nd salt water, accompanied by inflammable gas, is struck in the erea sandstone at 570 to 610 feet. In one of the borings gas had orked up into the base of the drift. No water was found below the rea sandstone, although one of the borings was carried to a depth 1,530 feet. These wells are discussed by Doctor Lane in the ınual Report of the State geologist for 1901.

At Vaughn wells ordinarily obtain a good supply of water at about feet, and they are of similar depth in the vicinity of Lott.

At Spruce, in the north part of the county, wells are obtained at oths of 20 to 25 feet or less, but several farm wells in that vicinity ve been sunk to depths of 80 to 100 feet.

Village supplies in Alcona County.

Town.	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
ona	590	Lake Huron, springs, shallow wells.	10	30	20	20	.....	Large.
afield	870	Au Sable River, springs, shallow wells.	40	40	40	40	−35	Strong.
ck River	590	Lake Huron, shallow wells	8	40	8	8	−4	Do.
ant	850	Shallow wells	20	30	25	25	.....	Weak.
nbush	640	do	25	30	25	25	−20	Strong.
tin	693	do	30	50	35	35	−30	Weak.
risville	600 640	Springs, shallow wells	10	40	30	.....	.....	Large.
naster	700	Wells	20	240	30	30	+20	Weak.
oln	770 810	Lake, shallow wells	30	40	35	35	−30	Do.
ıdo	634	Wells	30	70	30	30	−20	Do.
ngport	600 640	Mainly springs	30	40	30	.....	.....	Large.
ee	750	Shallow wells	15	30	25	20	−10	Weak.
ghn	1,000 1,025	Lakes, wells	20	80	30	30	−25	Do.

WATER SUPPLIES OF OSCODA COUNTY.

By Frank Leverett.

Oscoda County is situated west of Alcona County, with Mio as its county seat. About half its surface is occupied by sandy plains unsuited for settlement, and much of the remainder is in sharp morainic ridges of gravelly or sandy constitution not calculated for successful farming. There are, however, fertile tracts to the northeast near Fairview, to the northwest toward Redoak, and to the southwest between Mio and Luzerne. The entire population of the county in 1900 was only 1,468; Mentor Township, including the village of Mio, is credited with a population of 119. Au Sable River runs through the county nearly centrally from west to east in a valley 50 to 100 feet below the bordering sand plains, draining, with its tributaries, all of the county except a narrow strip on the north edge, which discharges northward to Thunder Bay River.

The drift is probably several hundred feet in thickness, but no wells have yet reached rock. Several in the vicinity of Fairview are over 200 feet in depth, and are largely through sand. At Mio the dug wells are 50 feet, and bored wells in that vicinity are 100 to 150 feet. There are few places in the county where wells can be obtained at less than 50 feet, except in the valleys.

The village of Mio has a public water supply, built in 1889, in which water is pumped from a spring brook to an elevated tank. It is credited by the Manual of American Waterworks with 0.6 mile of mains, four hydrants, and 18 taps, all of which are reported to have cost $2,844. This yields an annual income of $1,000 paid by the village for fire protection and about $100 from other sources.

Village supplies of Oscoda County.

Town or post-office.	Population.	Elevation.	Source.	Depth of wells.			Springs.
				From—	To—	Common.	
		Feet.		*Feet.*	*Feet.*	*Feet.*	
Comins	7	1,150	Springs and driven wells	28	100	40	Large.
Fairview		1,250±	Lakes, springs, wells	20	220	65	Do.
Mio	100±	1,000±	Waterworks, wells	50	102	95	Small.
Luzerne	50±	1,100±	Wells	50	70	50	Do.
McKinley		900	do	12	15		Large.
Redoak			Driven wells	16	30	20	Do.

WATER SUPPLIES OF CRAWFORD COUNTY.

By Frank Leverett.

Crawford County is situated on the high table-land in the northern end of the Southern Peninsula about midway between Lake Huron and Lake Michigan, Grayling being the county seat. Its western side drains westward to Lake Michigan through Manistee River, but

The major part of the county drains eastward through Au Sable River. Its glacial drainage, however, was westward past Portage Lake to Manistee River. This county, like Oscoda, is very largely occupied by sandy plains or by moraines of loose-textured drift. The principal part of the farming is in Maple Forest Township, in the northern part of the county, and three towns in that part of the county, Judge, Frederick, and Deward, are largely devoted to lumbering. There are several good farms in the southern end of the county a few miles northeast of Higgins Lake. The township in which Grayling is situated had a population of 1,716 in 1900, a large part of which are within the village limits.

The wells throughout the county appear to be to a water table in harmony with the inland lakes and streams, and the drift so far as penetrated by them is mainly sand and gravel.

In Grayling, which is on a plain but little above Au Sable River, the wells are 20 feet in depth, and water stands within 13 feet of the surface.

At Judge the conditions are very similar to those at Grayling, wells being commonly from 16 to 20 feet deep, or about to the level of the north fork of Au Sable River. On moraines near Judge a depth of 135 feet is reached by the deepest wells.

At Frederick, wells are about 40 feet in depth with the water level perhaps 25 feet below the surface. On the moraine east of Frederick, in Maple Forest Township, wells are usually nearly 100 feet and in some cases about 200 feet in depth, with but a few feet of water in the bottom.

At Deward, in the valley of Manistee River, wells need to be driven only 10 to 20 feet.

In the southern part of the county near Wellington the wells range from 30 to 200 feet in depth, the deepest being on morainic ridges, and the shallowest in valleys. On most farms, however, wells are obtained at 50 to 100 feet.

The distance to rock, as determined by a boring at Grayling, is 365 feet, making the rock surface 775 feet above tide at that point. The drift here is largely sand and filled with water. This boring, which reached a depth of 2,750 feet, is discussed by Doctor Lane in the report of the State geologist for 1901. The highest points in the county are nearly 1,400 feet and the drift beneath them is liable to be over 600 feet, if we may judge by the altitude of the rock at the Grayling well.

At Roscommon, just south of the county line, a boring was made many years ago which is thought to have reached rock at about the same level as that at Grayling, but no accurate record is now to be obtained.

WATER SUPPLIES OF KALKASKA COUNTY.

By FRANK LEVERETT.

General statement.—Kalkaska County lies west of Crawford County, on the western slope of the high tract in the northern part of the peninsula. Its eastern and southern parts are drained by Manistee River and its northwestern parts by Boardman and Rapid rivers. The part south of Manistee River has a small settlement around Fletcher, in the southeastern township, where there are a few square miles of good farming land, but the remainder has scarcely any settlers. The eastern townships north of the river have only lumber camps. The principal farming district in the county is on a morainic belt lying east of the Grand Rapids and Indiana Railway and running entirely across the county from its north border to its southwest corner. The railway runs through a sandy plain several miles wide that is largely unsettled. In the northwestern part of the county is another morainic belt which is nearly all settled. The northwest corner is on a low sandy plain bordering Torch and Round lakes.

Wells.—The only flowing wells noted in this county are in the southwestern part near Fife Lake. Walton Blue has a well in a valley near the center of sec. 7, Springfield Township, 22 feet in depth, which flows a weak stream. About a mile southeast, at an old sawmill site, in the western part of sec. 17, is a flowing well 63 feet deep, which discharges a 1-inch stream.

It is probable that flowing wells may be obtained in the vicinity of Rapid City and Barker Creek at the foot of the moraine in the northwest part of the county, for they have been obtained in similar situations a few miles to the west at Williamsburg and Traverse City. (See pp. 315-324.)

The wells in the Fletcher settlement go down 60 to 70 feet to water and have very little head.

In the moraine east of the Grand Rapids and Indiana Railway wells run from 40 to over 100 feet, the ground-water table being generally about on a level with the inland lakes and streams. The moraine is loose textured and largely gravel and sand below a few feet of surface till.

In the sand plain along the railway wells are also sunk to a general water-table in harmony with the streams and lakes, and range in depth from 10 feet near Kalkaska to about 80 feet in the northern part of the county. The moraine in the northwestern part has wells of various depths from 25 to 200 feet, there being no general water table. The deep wells, however, go to a level about as low as the sandy plain in the northwest corner. On that plain water is only a

'eet below the surface, or in harmony with Torch and Round

far as ascertained no wells have reached rock, and it is proba-
hat the rock surface lies at a depth of several hundred feet
ıghout the county.

'scellaneous village supplies.—Barker Creek is on the slope of
noraine south of Round Lake, in the southwestern part, at a
about 40 feet above the lake, or 630 feet above tide. Wells
n water at 16 feet, and there are large springs in the vicinity
h supply part of the residents.

,pid City is on the sand plain near Torch Lake, and has wells
20 feet deep.

ılkaska, the county seat, is on Boardman River, and wells are
ned at 10 to 24 feet. There is a waterworks plant, which
ɔs its supply from the river, and is mainly used for fire protec-
and street sprinkling. The water, both in wells and river, is
ɜnough for laundry and boiler use. In wells 10 to 16 feet deep
softer than in the deeper ones, probably because of more thor-
leaching of the upper part of the sand.

low are given two partial analyses,—one of a shallow-well water
ɔne of a river water at Kalkaska. There has been much typhoid
ıe town, and the shallow waters must be regarded as unsafe.
data were furnished by M. O. Leighton, of the United States
ɔgical Survey.

Partial analyses of well and river water at Kalkaska.

[Parts per million.]

	1.	2.
.....	107	10
'e).....	2.5	(a)
e (Cl)	9	9
dioxide (CO_2).....	66.17	60.55
r trioxide (SO_3).....	0	0
'ss (as Ca CO_3)	139+	132.1

[a] Very slight trace.

Lewis, analyst. 1. Pere Marquette Railroad; depth, 28 feet. 2. Boardman River.

etsville, though in the same sand plain as Kalkaska, is 50 feet
ɜr, and has wells correspondingly deeper, the usual depth being
et.

Westwood, which is north of Leetsville on the sand plain,
are 50 to 60 feet deep.

South Boardman wells are 18 to 40 feet, the town being on
ıneven slope of the moraine that lies east of the Grand Rapids
Indiana Railway.

Spencer and Sharon wells are only 12 to 20 feet deep, for they
ɔn low tracts bordering Manistee River.

WATER SUPPLIES OF GRAND TRAVERSE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Grand Traverse County is situated at the south end of Grand Traverse Bay, with Traverse City as the county seat. The south end of the county is occupied by an elevated moraine, with a southern outwash apron extending into Wexford County. North of this is a broad gravel plain traversed by Boardman River to the meridian of Traverse City, and continued westward, past a group of lakes near Interlochen, into Benzie County. This gravel plain is an outwash apron from a morainic belt that sweeps around the head of Grand Traverse Bay in the northern part of the county. Traverse City stands in a recess on the inner border of this moraine, and its numerous flowing wells are fed from the water absorbed by the moraine. The peninsula which runs northward between the arms of Grand Traverse Bay is occupied by a rather porous drift beneath the surface coating of till, so that underground drainage is very efficient.

Throughout much of the county the water table appears to be nearly as low beneath the moraines and elevated gravel plains as the surface of the neighboring streams and lakes, and wells ordinarily go to depths corresponding to the relief of the well mouths above the nearest stream or lake. On the gravel plain in the south part of the county, and the moraine of which it is the outwash, wells are ordinarily from 75 to 190 feet in depth, those near the crest of the moraine being deeper than on the plain to the south. Several wells around Summit City are over 100 feet in depth, but the common depth is 35 to 50 feet.

At Fife Lake and Walton, which stand but little above the drainage lines, wells are obtained at about 30 feet.

West of Traverse City is a prominent moraine in which the depth to water is in some places very great. Henry Sochleben has a well near the center of sec. 6, T. 27 N., R. 11 W., which is 293 feet in depth and was entirely through sand after penetrating about 5 feet of surface clay; water rises in it only 15 feet from the bottom. R. Wiedoft, on the west side of the same section, at a level perhaps 75 feet lower, has a well 220 feet deep, with but a few feet of water in the bottom. L. Ruthart, in the northwest part of sec. 5, has a well 230 feet deep which penetrated considerable blue clay and has 20 feet of water.

On the peninsula records of wells near the highest points show that water is struck at about the level of Grand Traverse Bay. Joseph Eiman has one 180 feet and William Ayers one 197 feet in depth in the northwestern part of sec. 10, T. 29 N., R. 10 W., both of which strike water in gravel practically at the level of Grand Traverse Bay. There are, however, wells on this peninsula which obtain a fair amount

of water at moderate depths, this probably being due to the presence of a nucleus of clay beneath the looser textured drift, which prevents the water from sinking down to the level of the bay.

The flowing wells of Traverse City and of Williamsburg, a village 2 miles east, are discussed below by Mr. Gregory. These, so far as known, are the only flowing wells in the county. It is probable, however, that flowing wells may be obtained along the north shore of the high moraine in the south, for the situation is similar to that at Traverse City and Williamsburg, and it is a region of strong springs. They may also be obtained some distance up Boardman River from Traverse City, and around Fife Lake, as they have already been found in the neighboring part of Kalkaska County.

MISCELLANEOUS VILLAGE SUPPLIES.

At Interlochen wells are driven to depths of 12 to 22 feet to a water table in harmony with neighboring lakes.

At Karlin the wells are about 40 feet and have very little head.

At Mayfield the depth ranges from 12 to 30 feet.

At Old Mission the wells are 20 to 50 feet deep.

At Summit City the common depth is 35 to 50, but the range in depth is from 14 to 112 feet.

At Monroe Center the wells are from 25 to 30 feet in depth.

At Cedar Run, in the northwest corner of the county, is a very strong spring, which supplies most of the inhabitants. The wells in that vicinity range from 8 feet to 150 feet, the deep ones being on the elevated land.

FLOWING WELLS.[a]

WILLIAMSBURG AREA.

The Williamsburg area, less than three-fourths of a square mile in extent (see fig. 61), is located on the banks of a small creek of eastern Grand Traverse County. With a general elevation of 690 feet this area is bordered by moraines and outwash plains having an elevation of 800 feet. The precise limits of the district have not been outlined, but few trials for flows have been made along the border of the area, which appears to be confined almost to the village itself.

Out of 23 wells in this region 20 flow, furnishing an abundant supply of water for domestic and stock purposes.

The first well was drilled in 1892, on the property of Mr. J. H. Bissell (No. 4), and is still flowing, with no perceptible decrease. The temperature, quality, and abundance of the water are such that it has been utilized by Mr. Bissell for a State fish hatchery. It is valuable for keeping in equable and natural condition the young fry. This use

[a] By W. M. Gregory.

of water could be profitably extended to some of the other flowing-well districts in the northern part of the State.

The wells are all driven; a few have screens and points, but the large number have simply galvanized pipes driven to the water beds. The average cost of the wells, with 2-inch pipe, is $1 a foot, though some cost less when made by the owners. The average cost here is somewhat higher than in other areas, owing to the fact that wells drive harder here and some trouble has been experienced with bowlders.

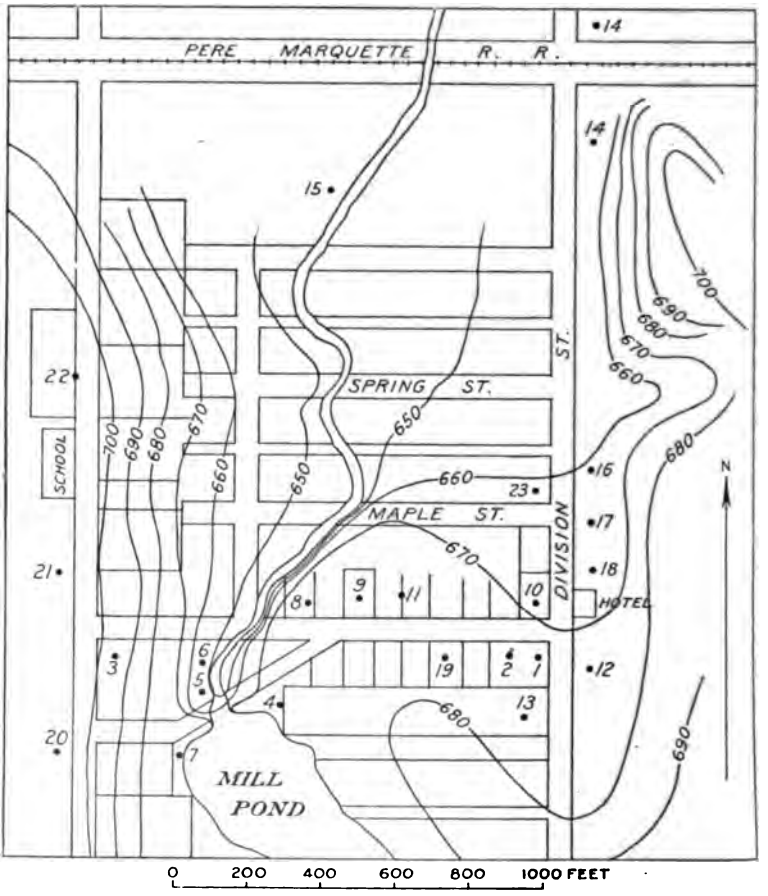


FIG. 61. Contour map of Williamsburg flowing-well district.

The combined flow of the 20 wells is 448.5 gallons a minute, t largest flow (130 gallons a minute) being at the fish-hatchery well (N 6). Several cases have been observed of decrease in head, due drainage of one well by a near neighbor tapping the same water be but no general change in flow has occurred.

The water beds which supply the wells at Williamsburg are two, t upper supplying the majority of the wells, for the lower has not be

enough to reveal its extent. The upper
is of gravel and sand, covered by a few
rdpan, 35 feet of clay with small sandy
l 10 feet of sandy soil at surface. The
lations of a water bed along an east-west
e shown in fig. 62. The wells, with the
of the fish-hatchery well (No. 6), are
for their supply on this bed of coarse
d sand. A section (fig. 63) north from
nson's well (No. 12) brings out clearly
et dip which the water bed has to the
t the 50-foot wells at the Williamsburg
indicate that this dip is not continued
rth as regularly as the profile indicates.
ot was made at the creamery to secure a
low by drilling deeper than 50 feet, but
s reported mostly hard clay from 50 to
with no water. Several attempts about
of this basin have been made to pene-
water beds. At Mr. Lidell's farm a well
00 feet deep failed to secure water, which
be due to the fact that the water beds are
urface and are easily overlooked in drill-
s happened in other locations.

ation of Williamsburg is on the northern
side of high plains of morainal outwash,
ch an elevation of 800 feet just outside
of the village. The small creek of the
the product of the numerous springs
so abundant along the edge of the drift
ation of 740 to 760 feet above sea level.
ith there is abundant chance for a catch-
in the loose porous drift, which has clay
n, as is indicated by some of the small
ch exist there.

ter is used throughout the village for
nd domestic purposes, and is not consid-
l, lathering freely with ordinary soap.
shows its hardness to be near that of the
drift water. Sulphates and iron seem to
t, and the two field analyses of samples
s No. 16 and 2 show how water from
bed is apt to differ in carbonates. The
very free from surface contamination, and is an excellent
ater. Its temperature, purity, and freedom from silt are of
lue in this region for the fish-hatchery business.

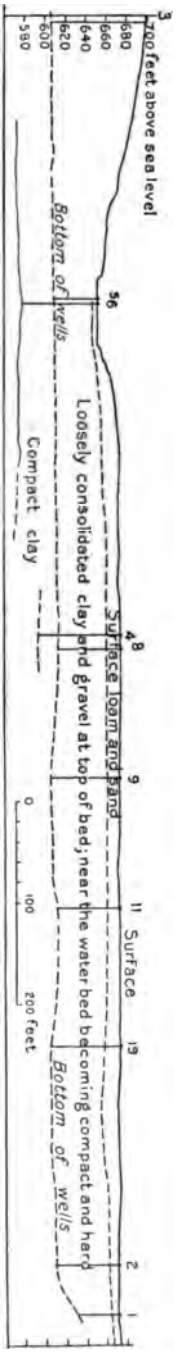


FIG. 62.—East-west section through Williamsburg district.

Analysis of water from well at Williamsburg.[a]

	Parts per million.
Silica (SiO_2)	8.40
Sulphate radicle (SO_4)	7.32
Carbonate radicle (CO_3)	90.44
Chlorine (Cl)	2.67
Sodium (Na)	1.89
Potassium (K)	.31
Calcium (Ca)	46.85
Iron (Fe)	5.95
Aluminum (Al)	2.86
Magnesium (Mg)	9.93
Lithium	Trace.
Organic matter	Trace.
	176.53

Analyst, John E. Clark, M. D., Detroit College of Medicine.

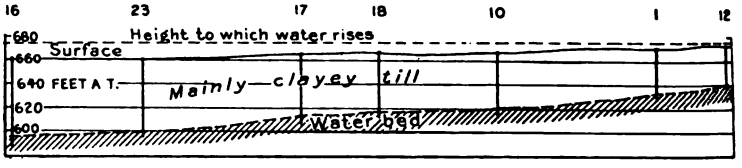


FIG. 63.—North-south section through Williamsburg district.

Analysis of Weesh-Ko-Wong flowing well water, Williamsburg.[b]

	Parts per million.
Silica (SiO_2)	8.40
Aluminum (Al)	2.78
Iron (Fe)	6.00
Calcium (Ca)	46.77
Magnesium (Mg)	9.96
Sodium (Na)	1.78
Potassium (K)	.34
Sulphate radicle acid (SO_4)	7.42
Chlorine (Cl)	2.67
Carbonate radicle acid (CO_3)	90.33
	176.45

Analyst, John E. Clark, M. D., Detroit College of Medicine, March 6, 1893.

Field analyses of water from wells at Williamsburg.

[Parts per million.]

	1.	2
Hardness	148	178
Carbonates	110	160
Chlorides	5	10
Sulphates	0	0
Iron	0	0

1. Charles Wills (No. 16). 2. Dr. Prentice (No. 2).

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Wells at Williamsburg.

Owner.	Elevation.	Diameter	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
	Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gls.*	° *F*			
D. E. Rolf [a]	673	1½	40	633	.....	30	48¼	Soft...	$12	Made in 12 hours.
Dr. Prentice	673	1	60	613	.....	28	48	.....	60	See analysis (p. 318).
Dr. C. A. Clark	700	1½	96	604	701	25	49	Soft...	90	Flow decreased by No. 6.
J. H. Bissell	673	1½	82	591	683	10	48	.....	82	See analysis of Weesh-Ko-Wong well (p. 318).
Fish hatchery [b]	655	2½	45	610	.....	12	....	.....	45	Water flowed around pipe.
Fish hatchery [c]	655	4	87	568	680	130	48	.....	200	
J. Abbott	672	1½	42	630	.....	10	....	.....	130	
Ralph White	675	1½	60	615	680	13	48	Soft...	60	Head said to be decreased by No. 6.
James Ernest	674	2	65	609	.....	13	....	.....	.....	
F. E. White	669	2	55	614	673	10	48	.....	.....	
S. J. Seeley	673	2	60	613	.....	12	....	.....	55	Sand 10 feet at top; remainder sand and clay.
B. Johnson	672	2	35	637	676	6	....	Soft...	35	
Methodist Episcopal parsonage.	675	1½	43	632	.....	25	49	...do..	40	
Williamsburg creamery. [d]	658	....	45	613	.....	.....	....	.....	.....	Flow not estimated.
A. Devries	650	2	60	590	.....	6	....	.....	.....	
Chas. Wills [e]	660	2	64	596	674	30	48	.....	30	Head, 14 feet; see analysis.
W. Herald [f]	664?	2	55	609	.....	46	48	.....	25	
H. Hobbs [g]	665	....	50	615	674	15	50	.....	25	
Dr. Van Stickle	672	....	60	612	.....	12½	48	.....	30	Decreased by Nos. 5 and 6.
Lidell farm	705	2	400?	305	.....	.....	....	.....	.....	No water; said to be mostly clay from near surface.
Bissell farm	703	....	100	603	.....	.....	....	.....	.....	No flow.
J. Lidell	705	....	116	589	.....	.....	....	.....	.....	[h] Do.
T. J. Conklin [h]	660	2	62	598	.....	15	49	.....	50	Made in 1903.

Water rose 18 feet at time of drilling; has decreased to 3 feet now. Beds penetrated as follows: 'k loam and sand, 10 feet; sand and clay, 30, and water in gravel bed, 40 feet. Well driven in 15 rs; throws sand.

Two wells at fish hatchery have some sand at top, and the remainder is clay, with sheets of sand, ch contain no water, but are a hindrance in drilling. Water from bed of gravel with some sand; w water bed is a compact clay bed 20 to 30 feet thick.

Water broke out about pipes, and has required many cubic yards of filling, making the cost high. perature said to be 43° November 1, 1903.

Three wells, 45, 49, and 50 feet deep. Attempt was made here for deep water supply; went 310 feet, lay, no water.

Head 14 feet; affects other wells in near vicinity.

owered by No. 16.

ctual depth not known.

and 10 feet; clay, with sandy sea ns, 40 feet; hard, compact clay 8 feet; gravel water bed.

TRAVERSE CITY.

The flowing wells of Traverse City are confined to a small area of square miles in Farfield Township at the head of West Grand averse Bay. This region is a depression in the drift which was ed by an ice tongue of the Michigan lobe and was later covered Glacial lake deposits of considerable thickness, as revealed by ep wells in Traverse City. Flows are obtained at from 50 to 400 t in depth, and at present are 19 in number, yielding abundant d excellent water. These wells are in drift material, and casing necessary, as much sand is encountered and causes considerable noyance. The wells vary from 3 to 8 inches in diameter and

cost on the average about $1 a foot, the work being done by contract for a flow.

The total flow from these wells is 1,092 gallons a minute, the figures being based on measurements made by well drillers at the time of completion of the various wells and by the writer when the wells were freely flowing. In a special report of the water supply committee of the Traverse City council, Mr. G. W. Rafter, the consulting engineer, expressed doubt as to the ability of flowing wells to furnish a sufficient quantity for a city supply, but a flow of 1,092 gallons a minute would be ample. A few of the wells have decreased considerably. The Park Place Hotel well, for instance, now yields only half its former flow, according to Mr. Fairbanks, a well driller of Traverse City. The first well in this city was made on the grounds of the Northern Michigan Asylum in August, 1897, and flowed 600,000 gallons a day from a depth of 93 feet. In April, 1890, this flowage suddenly ceased; investigation showed that the pipe was filled with clay; by driving to 190 feet a good supply was reached. This well, with another recently made, 100 feet deep, now supplies the institution with 400,000 gallons a day, much more than is needed. In the well on the asylum ground the pressure is 8.75 pounds at the well head, which is 70.25 feet above the engine room of the institution, where the pressure is said to be 40 pounds to the square inch. The total cost of the well and pipe line was $1,500 and was made by contract. The wells are 135 feet above Lake Michigan, on the slope west of the asylum buildings, and were discovered by workmen in making an excavation for a standpipe. The well on the Lion saloon property is carefully piped, and supplies a bottling factory, several stores, a saloon, and a large fountain. Water rises 8 feet from the end of a 1-inch nozzle on 20 feet of hose attached to the main pipe at the saloon, and at time of drilling the well spouted a 2-inch stream 32 feet above its mouth. More use would be made of the artesian water in Traverse City if it were not for a city ordinance prohibiting pipes from crossing alleys and streets.

Several analyses and a number of careful field tests have been made of the waters. Mr. George Rafter considered the water rather hard for boiler use, and the amount of iron rendered it rather undesirable for laundry purposes. The water from the Park Place Hotel has the following composition:

Analysis of water from Park Place Hotel well, Traverse City.[a]

	Parts per million.
Silica (SiO_2)	6
Calcium (Ca)	48.55
Magnesium (Mg)	9.88
Iron (Fe)	1.53
Sodium (Na)	2.25
Chlorine (Cl)	3.45
Sulphate radicle (SO_4)	1.20
Carbonate radicle (CO_3)	106.54
	179.40
Free ammonia	.15
Albuminoid ammonia	.08

Hardened by soap test, 12; permanent hardness, 6; temporary hardness, 6.
Doctor Kedzie, analyst.

The analysis shows nitrites entirely absent and nitrates present only as a trace.

The field tests on samples from the Park Place Hotel well show carbonates to be 170 parts per million, no reaction for sulphates, 170.8 parts of hardness, and chlorides 5.2 parts per million. An analysis by the Northern Michigan Insane Asylum of the water when it came from the 93-foot well is as follows:

Analysis of water from well of Northern Michigan Insane Asylum, Traverse City.[b]

	Parts per million.
Silica	34
Oxide of iron and aluminum	5.10
Carbonate of lime	168.75
Carbonate of magnesia	68.47
Sulphate of lime	27.04
Sodium and potassium chlorides	Trace.
Sodium and potassium carbonates	10.27
	313.63

The Lion saloon well had a total hardness of 178.8; carbonates 200, chlorides 25.4, and iron 2 parts per million. For the comparison the analysis of water from a spring on the land of Hannah Lay & Co., south of the asylum, is given:

Analysis of spring water near Traverse City.

	Parts per million.
Sulphate radicle (SO_4)	2.12
Carbonate radicle (CO_3)	82.14
Magnesium (Mg)	.17
Sodium (Na)	.39

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

	Parts per million.
Chlorine (Cl)	.61
Calcium (Ca)	56.17
Silica (SiO_2)	3
Free ammonia	2
Albuminoid ammonia	1.5

The two water beds which have been utilized to supply the present wells are at depths of 450 to 350 feet and at 200 feet, respectively, above tide. The upper of the two beds furnishes the greater supply and the best pressure. The following wells are supplied from this bed: Traverse City high school, Jackson's fish house, William Brothers, P. Hannah, Park Place Hotel, Lion saloon, and the old well at the Grand Rapids and Indiana depot. At the high school the following order of drift material was found:

Record of high school well, Traverse City.[a]

	Thickness (feet).
Sand	30
Clay	40
Sand and gravel	60
Marl	5
Gravel and first flow at	238
Stronger flow at	270

In drilling wells down to this first bed the usual order is 100 feet of sand with small streaks of clay, succeeded by 200 feet of gravel, sand, and clay, which becomes hard and compact 250 feet below the surface. In drilling the new well at the depot the drillers found a good flow at 316 feet and a fair one at 417 feet, both beds being utilized for the flow in this well. The two wells of E. S. Pratt, which are situated on hills west of the city, are believed to tap heavy springs such as were found in the early exploration for water on the State asylum ground. A number of wells have been made on a lower level to a depth of 75 feet, east of E. S. Pratt's place, but the water stands 20 to 30 feet below the surface. The wells which have been drilled below the 300-foot bed do not furnish a very satisfactory supply. The well at the county jail is 400 feet deep, but never rose more than to the surface; in drilling it the following drift was found:

Record of well at county jail, Traverse City.

	Depth (feet.)
Sand and some marl	200
Clay	200–232
Sand and clay alternately	252–340
Gravel	340
Sand and water	390–400

[a] For analysis see Water-Supply and Irrigation Paper No. 31, U. S. Geol. Survey, 1899, p. 30.

The well at the Boardman Avenue school is said to be nearly all ıd, with a little clay at the bottom. The well recently made for the and Rapids and Indiana Railway is 417 feet deep and has a good w, but the larger part of it is evidently from the upper bed. Many empts have been made to get water at the Oak Park school, in the ıtern part of the city, one well being drilled to 400 feet, and at pres- t having a very small flow. In this well the following material was netrated:

Record of Oak Park school well.

	Depth (feet.)
ıd (thickness)	30
y (thickness)	60
ıter in sand (depth)	220
d clay (depth)	363–383
ıvel and small flow (depth)	383–400

The well on the property of Ellis Ramsell was drilled through the llowing material:

Record of Ellis Ramsell well.

	Thickness.	Total.
	Feet.	*Feet.*
nd	60	60
avel	60	120
ıy	40	160
nd and gravel	20	180
ırdpan	50	230
ıy, water under clay	60	290

At the State asylum Mr. Fairbanks helped to drill the 93-foot well ıd found nearly 35 feet of sand and gravel, the remainder being hard ıy, under which was the water. At 75 feet a log 3 feet in diameter ıs encountered.

In seeking for flows in this area the wells should not be deeper than 0 feet, and the lower the elevation of the well mouth the greater ll be the pressure.

No rock has been reached in any of the Traverse City wells, but in e Provement well at Fountain Point, some 12 miles northwest of averse City, it is nearly 312 feet to rock, and at Elk Rapids some miles northeast it is 450 feet.

The catchment area for the Traverse City wells is found on the sur- ınding moraines and associated plains of porous overwash material, ıich reaches an elevation of 800 to 1,000 feet in the region west and ıth. In the immediate vicinity the material exposed on some of the ls is porous enough to absorb the necessary water to supply the ·ong flows.

Wells at Traverse City.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.[a]	Remarks.
	Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*	
Lion saloon	605	6	307	248	670	210	49½	Flow from gravel.
Grand Rapids and Indiana depot (new).	605	.....	417	187	640	54	51	Steaming and drinking.
Park Place Hotel	605	3	357	248	630	25	50	Drinking fountain.
P. Hannah	.....	4	350	.....	.....	63	.....	Domestic use.
County jail	605	.....	400	205	605	.....	.....	Small flow.
E. S. Pratt	659	8	50	609	665	80	.....	Domestic use.
Williams Bros.	625	.....	367	258	645	112	.....	Flow from gravel.
State Insane Asylum	715	.....	290	527	735	277	.....	Drinking.
Oak Park school	615	4	400	215	615	2	.....	Do.
Jackson fish house	605	4	300	305	635	50	49	Fishing, packing.
E. R. Ransom	.....	.....	486	.....	.....	.....	.....	
Boardman school	620	.....	235	390	628	5	.....	12 feet in block shale.
Grand Rapids and Indiana (old well).	605	6	311	284	630	45	49½	
Carter's mill	585	.....	180	405	585	1	.....	Small flow.
Mr. Broadhagen	635	3	330	305	655	90	.....	At house on Washington street.
High school	612	4	271	341	656	.....	.....	Pressure of 17 pounds.
Wilhelm Bartok Co	592	.....	280	.....	603	15	.....	
Ellis Ramsell	.....	.....	.....	280	.....	.....	.....	

[a] The only satisfactory temperature observation was at the Grand Rapids and Indiana depot well (new). The others are affected by buildings, etc.

WATER SUPPLIES OF BENZIE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Benzie County, of which Frankfort is the county seat, fronts on Lake Michigan in the northwestern part of the peninsula. The lake shore presents a succession of headlands 200 to 300 feet high, between which are low embayments extending back several miles inland and terminating in a strong morainic belt of which the headlands are small interlobate spurs. The interior and eastern part of the county is a somewhat elevated plain with numerous lakes and basins interrupted by groups of knolls. The altitude of the plain is between 200 and 300 feet above Lake Michigan, and the lakes on it usually stand 30 to 50 feet below its general surface. The water table on the plain and also on the knolls appears to be in harmony with the neighboring lakes and drainage lines, for there is but little clay in them above the level of the lakes. The water table also is at a low level throughout much of the morainic region of the western part of the county. This is well shown at Benzonia, which stands on a moraine south of Crystal Lake at a level 200 feet above the lake, and has a water level at least 125 feet below the surface. There are, however, a few places in the morainic tracts where there is enough clay present to prevent the downward passage of the water, and thus permit wells to be obtained at shallow depths.

The principal streams are Betsy and Platte rivers, the former aining the southern and the latter much of the northern part of the unty. Between their mouths and near the shore of Lake Michigan ands Crystal Lake, a body of water 9 miles long and 2 miles wide, nnecting with Betsy River through a narrow gap in the morainic ls that encircle the lake. Platte River discharges through Platte .ke, a body of water covering several square miles, just before enter- g Lake Michigan. These lakes apparently occupy basins of con- lerable depth which were left by the ice sheet. The lakes of the terior of the county are all small and are usually in basins in the avel plains.

The drift in this county is shown by borings at Frankfort to extend wn nearly to sea level, being 570 feet in one boring and 527 in nother. The rock surface seems to be about as low to the east at raverse City, and may hold a low level beneath the high tracts which between Frankfort and Traverse City, in which case the drift ould have a thickness of about 1,000 feet on the highest points.

FLOWING WELLS.

The embayments along the shore in the recesses of the moraine fur- ish favorable places for obtaining flowing wells, and such wells have lready been made at Frankfort on Betsie River, at Beulah on Crystal ake, and at Honor on Platte River, while others may be found near ne Herring lakes in a recess a few miles south of Frankfort. There also a single flowing well at Thompsonville in the southeastern part f the county, in the valley of a small stream. The wells at Frank- rt and Beulah were examined by Mr. Gregory and are discussed on ages 327–330. The well at Thompsonville was reported by Mr. V. F. Cooper; those at Honor were examined by the writer.

THOMPSONVILLE.

The Thompsonville flowing well was made by John Irwin and has depth of 150 feet, with a head of 5 feet.

HONOR.

The village of Honor stands at the foot of the north bluff of Platte ver in northern Benzie county. Several flowing wells have been ade in the eastern part of the village, all very near the bluff on ound a few feet above the broad valley bottom. It is probable that ws could be obtained on this lower ground.

George Weaver has a well 70 feet deep on ground about 9 feet above e railroad station, or 620 feet above tide. It has a head of more an 4 feet. It now escapes around the pipe, and this has reduced e flow through the pipe to a very weak stream—about 10 quarts

an hour. It did flow a half-inch stream. The water is hard and has considerable iron. The temperature is 47.3° F.

South of this well about 50 yards is the flowing well of Ira Gordon, 38 feet deep. It flows a very weak stream—about 15 quarts an hour at a level 3 feet above the surface or 622 feet above tide. The water is said to be rather soft. The well struck a hard clay under the surface gravel at about 20 feet and obtained the water from a seep in the clay. The well has never been much stronger. The temperature is 48° F.

At a dwelling occupied by W. M. O'Brien on the south side of Main street is a flowing well only 21 feet deep which yields about 30 quarts an hour through a small escape pipe one-third of an inch in diameter. The altitude of the well is 618 feet above tide. The temperature was 48.5° F. in October, 1904. Possibly the effect of the summer heat would be felt in a well so shallow as this and give it a temperature higher than that of deeper wells or higher than it presents at the cold part of the year.

At another dwelling on the south side of Main street, occupied by Frank Weaver, is a flowing well that yields about 3 quarts a minute and has a temperature of 47.8° F. This is the oldest flow in the village and has been in operation about eight years. The water contains iron in notable amount and is so hard that it needs softening for laundry use. The well is at an altitude of 617 feet.

On the north side of Main street, about 100 yards east of the well just noted, is a weak flow at the dwelling of Joseph DeWitt now yielding about 30 quarts an hour—about as much as it ever did. It is very shallow—15 feet—and had a higher temperature than the deeper wells, it being 49° F. The water carries iron, but is not very hard. The well has been in operation about 7 years. The altitude is 618 feet.

Across the street from the DeWitt well and on ground 3 feet lower at a dwelling occupied by V. Pierce but owned by P. Reynolds, is a flowing well 21 feet deep. A pump is now attached because the head is very slight. The well was made in 1903.

A similar well, only 13 feet deep, with water rising barely to the surface, was made by J. C. Van Blaricom about 200 feet west of the Pierce well. It passed through a bed of clay at 6 to 13 feet and entered gravel at bottom. The water is rather hard.

Mr. Van Blaricom has another well at the post-office, with pump attached, but with a head of about 2 feet. This well is 23 feet deep. Its temperature, when pumped vigorously, could not be carried below 48° F. The altitude is 622 feet at the post-office. West from the post-office the dwellings are mainly on ground a little too high to admit of a flow.

BEULAH AND BENZONIA.[a]

Beulah, Benzie County, in a narrow belt along the eastern shore ystal Lake, is a small area with seven flowing wells (fig. 64). wells have a total flow of 56 gallons a minute and no indications y decrease in head have been observed. The best head of water tained in wells nearest the lake. The irregular flow of a well at l's livery barn is due to the presence of gas which, at the time of writer's visit in July, 1904, was forcing small quantities of water of the well at frequent intervals. The water supplied by these is hard and unsatisfactory for laundry use, but excellent for

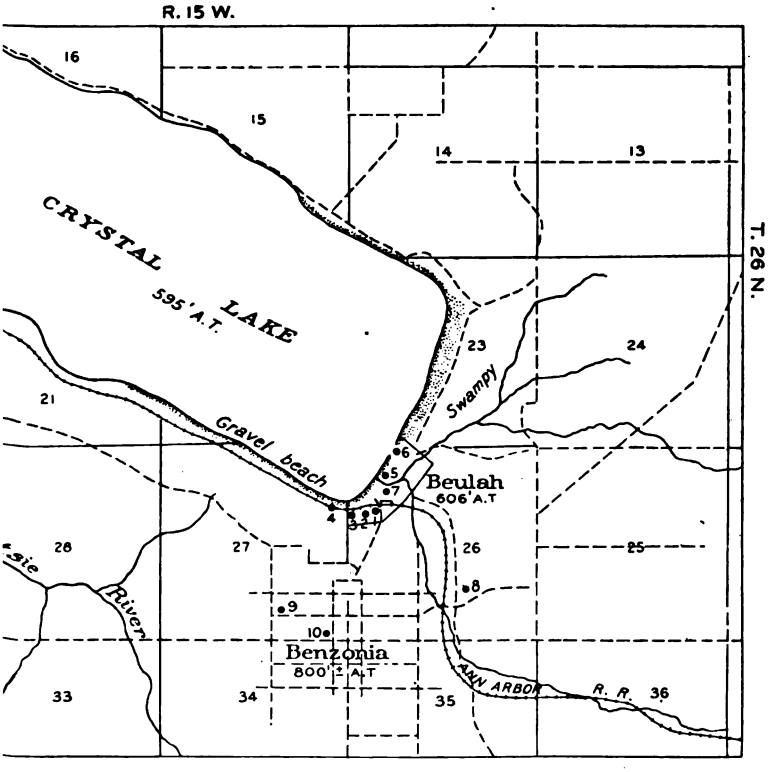


FIG. 64.—Map of southeast end of Crystal Lake, Benzie County.

ting. The best supply in Beulah comes from the beds 100 to 150 below the level of Crystal Lake, the depth varying in different

e field analyses of samples collected show that the waters are in carbonates, reaching 300 parts a million in one case (the well . A. Bailey, No. 5), but this is higher than the average. Sul- es are absent from all the water tested, and chlorides are present rying quantity, 34 parts per million from a well belonging to

[a] By W. M. Gregory.

Mr. Gibbs being the highest found. In several of the wells much CO_2 was present, especially in the Gibbs well. The water is somewhat harder than water at Oden, Indian River, and Williamsburg, varying from 136 parts per million in H. A. Bailey's well to 361 parts in J. Gibbs's well. It is easily sofened for laundry purposes by any of the various washing compounds, otherwise much soap is required. Water from the well of H. S. Bozy (No. 6) requires one-half more soap for laundry purposes than water from Crystal Lake. The flowing well water is excellent for drinking and in the well of Mr. H. Smith (No. 4) the water has mild cathartic properties.

Field analyses of water from wells at Beulah.

[Parts per million.]

	1.	2.	3.
Hardness	136	361.8	227.8
Carbonates	300	240	120
Chlorides	4	34	8.9
Sulphates	0	0	0
Iron	.....	0	0

1. H. A. Bailey (No. 5). 2. J. Gibbs (No. 1). 3. H. Smith (No. 4).

In the houses where the water is used small tanks have been constructed so that full advantage may be taken of its temperature for cooling purposes. The temperatures vary slightly in the wells because of the difference in the length of pipe exposed, but the average is 49°.

Two beds seem to be present in Beulah which yield flows. The extent and thickness are unknown, for the well records are few and lack detail. According to Mr. N. Benson, a well driller of Beulah, the first bed of sand and gravel is 90 to 100 feet below the surface; the second bed ranges between 150 and 200 feet. The well of Mr. H. Smith (No. 4) is 97 feet deep, 94 feet to water, and has the following drift layers:

Record of H. Smith well, Beulah.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	3	3
Gravel	6	9
Yellow clay	20	29
Gravelly hardpan	25	54
Blue clay	40	94
Black clay and gravel	2	96
Gravel	1	97

In the well on the property of Mr. Small (No. 7) small flows are found at 150 and 200 feet. The well was drilled to 250 feet and was believed to be nearly to rock. The present flow of this well comes from 200 feet, but enough gas is present to cause an irregular flow.

ı shallow pump wells of the town have never yielded a good sup- of water, being deficient in quantity, and having a "swampy" ;e. In drilling a well on the property of Fred Bailey (No. 3) the owing drift was penetrated:

Record of Fred Bailey well, Beulah.

	Thickness.	Total.
	Feet.	*Feet.*
rel and sand	27	27
k shells and cedar wood	5	32
›w clay	20	52
clay	50	102
;el	8	110

Mr. Benson, a well driller, thinks that good flows can be obtained ng a large part of Crystal Lake at points less than 20 feet above ı lake.

.n the town of Benzonia, which is half a mile south and 180 feet 'her than Beulah, the water bed is from 100 to 150 feet below the ·ous surface material, water being obtained at considerable expense. Mr. T. B. Pettit's well, in Benzonia, 176 feet above Beulah, is ven 190 feet, and the water stands 175 feet below the surface; the ;ire cost was $230. Mr. Pettit has another well in sec. 27, near nzonia, which is 85 feet deep and in which the water stands 75 feet ow the surface. The soil here is largely sand and gravel with one y bed of 19 feet near the surface. The village well of Benzonia 213 feet deep, the lower 150 feet of which is fine clay and yields a nt supply of water.

The hills about Crystal Lake consist of loosely consolidated drift h irregular beds of clay. In a cut 100 feet above the Ann Arbor ilroad depot, on the steep hill road from Beulah to Benzonia the y layers are thin, small, and irregular, but at lower elevations the y is present in thicker layers, and seems to have been plastered ›n the overwash material at places. A section on the hill road the following layers exposed:

Section in road near Benzonia.

	Thickness (feet).
l	3
›les	1
and sand	10
l	5
oth clay, large, rough, rounded pebbles	8

Wells at Beulah and Benzonia.

No. on fig. 64.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	J. Gibbs	609	2	150	459	613	8	47½	.....	Drilled in 1900; screen; see analysis (p. 328).
2	J. Thompson	607	2	100	507	.....	5	.....	.....	
3	Fred Bailey	608	2	110	498	.....	2	49	.....	Flow varies.
4	H. Smith	609	2	97	512	628	12	49	.....	See analysis.
5	H. A. Bailey	607	2	166	441	627	10	50	$125	Drilled in 1901; water at 166 feet.
6	H. S. Bozy	600	2	180	420	619	19	50	.....	Water hard.
7	F. S. Small	605	2	222	383	.....	.....	.....	.....	Flowage irregular.
8	E. J. C. Ellis	.....	2	213	.....	.....	.....	.....	.....	91 feet to water; pump.
9	T. B. Pettit	.....	2	190	.....	.....	.....	.....	230	175 feet to water; pump and windmill.
10	Benzonia village	.....	.....	213	.....	.....	.....	.....	.....	Lower 150 feet solid clay; weak well.

FRANKFORT AREA.[a]

The city of Frankfort, in Benzonia County, is situated at the mouth of Betsie River, on Lake Michigan. Only a few flows are found here in the drift, which is about 550 feet deep, the best water beds being 150 to 200 feet below the surface. There are only four of these drift wells, two at the Frankfort City waterworks, each 150 feet deep, one at the Ann Arbor Railroad grain elevator, 100 feet deep, and one at the Ann Arbor Railroad depot, 200 feet deep; the combined flowage is 7.5 gallons a minute. A sample of the water from the elevator showed 278 parts per million of hardness, no sulphates, 260 parts of carbonates, and 15.5 parts of chlorides.

Frankfort has two deep wells from the rock, both belonging to D. B. Butler. The deeper one is 2,200 feet, with a temperature of 58°, and flows 480 gallons a minute from a 6-inch pipe. It contains H_2S gas.

Wells at Frankfort.

Owner.	Diameter.	Depth.	Flow per minute.	Temperature.	Remarks.
	Inches.	*Feet.*	*Gallons.*	°*F.*	
D. B. Butler	4	1,800	.....	.....	Mineral water.
Ann Arbor Railroad depot	2	200	1.5	50.5	Drinking fountain.
D. B. Butler[a]	6	2,200	480.0	58.0	Mineral water.
Ann Arbor Railroad elevator	2	100	1.0	48	Drinking and boiler use.

[a] For analysis of water see Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, p. 72.

WATERWORKS.

FRANKFORT.

The waterworks supply is from driven wells about 90 feet deep which only lack a few feet of flowing. The water is pumped to a tank on a hill north of the town.

[a] By W. M. Gregory.

THOMPSONVILLE.

village of Thompsonville has a public supply reported to be driven wells, about 60 feet deep, in which water rises to 10 feet the surface. Water is pumped direct to mains.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies of Benzie County.

vn.	Population.	Elevation.	Source.	Depth of wells.			Depth to main supply.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
a	500	800	Driven wells	125	250	200	225	−100 −150	Large.
		600 615	Driven wells, some flowing.	20	150	100 150	100	Flow	Do.
rt	1,465	595	Driven wells	45	2,200	90 150	200	− 5 +10	Small.
sad		805	do	8	100	50			
	550	611	Driven wells, stream	12	40	30	30	+ 8	Do.
in	241	816	Lake wells, springs	20	90	30	30	−15	Large.
ity	±100	885	Driven wells	10	30	18	30		Small.
		700	do	10	+200	75		-10	Do.
rankfort	639	600	do	30	90	30	30	−10	Do.
onville	893	791	do	16	150	40		−10 + 5	Do.

WATER SUPPLIES OF LEELANAU COUNTY.

By Frank Leverett.

eral statement.—Leelanau County comprises the point of land extends northward between Grand Traverse Bay and Lake gan and also the Manitou Islands which lie a few miles off Like Benzie County, it presents bold headlands along the between which are low tracts extending back several miles eading in a moraine of which the headlands are considered This moraine comes up from the southwest and curves around southern part of Leelanau County and then passes southeast head of Grand Traverse Bay. An elevated gravel plain about et above Lake Michigan lies on the south border of the moraine. ighest points on the moraine are about 400 feet above Lake gan, and at Sleeping Bear Point there is a bold bluff of nearly eight. In the recesses between the headlands are lakes, con- us among which are Glen Lake, which lies east of Sleeping Point and has an area of about 6 square miles, and Carp Lake, leads south from Leland and is about 15 miles long. Between is a chain of lakes extending back nearly to Maple City. On st side are small projections of Grand Traverse Bay, known as port Bay and Sutton Bay. The latter is similar to the recesses Lake Michigan shore in having headlands on each side.

The county has no rivers nor creeks but simply small runs leading down to the lakes from the moraines.

On the elevated morainic tracts and also on the gravel plain in the southern part of the county wells are usually deep, ranging from 80 feet on the gravel plain to 240 feet on the crest of the moraine. They reach about to the level of the neighboring lakes, and have little or no rise of water. There are wells 80 to 150 feet deep along the ridges that run from the moraine out toward the lake and bay. These ridges, however, contain clayey drift, and in places shallow wells are obtained on them. In the lowlands or recesses water in wells generally rises nearly to the surface, and in places will flow. It is probable that flows might be obtained at many points if borings were made in the lowest lands near the high ridges.

In one boring in the county, made in 1853 near Provement in sec. 36, T. 30 N., R. 12 W., rock was found at a depth of 312 feet, or 292 feet below the level of Lake Michigan and 288 feet above sea level.[a] It is reported that limestone rock outcrops at the northeast end of the county in the bed of Grand Traverse Bay at 20 to 25 feet below the water surface, and shale rises to considerable height in the east bluff of the bay opposite this point.

Flowing wells.—The well near Provement, noted above, which is now the property of Mrs. Florence Whitfield, of Ann Arbor, is about 780 feet deep, and flows with a reported head of 40 feet, or about 60 feet above Lake Michigan. It discharges with such force as to form an umbrella-shaped sheet, and to run a small brook, estimated at several barrels a minute. It is strong in sulphates with a considerable amount of H_2S gas and also CO_2.

It is reported that the flow of water was struck in the upper part of the rock, but no definite data in addition to those published by Winchell could be obtained. There was a deposit of sand, gravel, and bowlders for 146 feet from the surface, beneath which was laminated clay for 135 feet, and beds of sand and clay for 25 feet. The water here came in and kept increasing until the rock was entered at about 312 feet.

Whether flowing wells could be obtained in this valley along Carp Lake at less depths has not been determined. The topographic situation in a valley between prominent drift ridges seems favorable for obtaining flows.

The Empire Lumber Company has a flowing well 54 feet in depth at its mill on the shore of Lake Michigan in Empire. The water comes from gravel under sand and possibly under clay. The water rises only about 8 feet above the lake.

Miscellaneous village supplies.—The villages are all situated on low ground and consequently have shallow wells. No town has a com-

[a] Record by A. Winchell, Proc. Am. Assoc. Adv. Sci., 1875, p. 31.

lete waterworks system, but at Suttons Bay N. S. Johnson has provided for a partial supply by damming a spring brook. A larger dam and complete waterworks are contemplated.

Village supplies in Leelanau County.

Town.	Population.	Elevation.	Source.	Depth of well. From—	Depth of well. To—	Depth of well. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Empire	609	586, 620	Driven wells, Lake Michigan.	25	75	35	.....	+ 4	Large.
Leland	±300	600	do	18	18	18	18	−20	Do.
Maple City	±200	±700	Wells and springs	16	90	.....	80	−28	Do.
Northport	545	610	Wells, springs, bay	12	100	25	100	[a]− 5	Do.
Omena	±300	610, 700	Wells and bay	20	200	100	100	−25	Small.
Solon	.....	625	Driven wells, springs	15	235	15	.....	−10	Do
Suttons Bay	398	600	Pond by waterworks, wells, and springs.	17	70	30	.....	−20	

[a] The postmaster at Northport has a well 90 feet deep that flows at 5 feet below cellar floor.

WATER SUPPLIES OF ANTRIM AND CHARLEVOIX COUNTIES.

By Frank Leverett.

GENERAL STATEMENT.

These two counties, which stand east of Grand Traverse Bay, are treated together, since they are so much alike. The part of Emmet County south of Little Traverse Bay is also included in the same description.

This district between Grand Traverse and Little Traverse bays contains a radiating system of finger lakes separated by prominent ridges, upon which drumlins have been developed. The lakes apparently lie, in part at least, in deep pre-Glacial valleys whose bottoms are 200 feet or more below the level of Lake Michigan. The ridges between have limestone exposed along the borders of Lake Michigan and Little Traverse Bay in Charlevoix and southern Emmet counties. Upon passing back to the southeast, Devonian shale sets in, which, in places, reaches an altitude of 120 feet or more above Lake Michigan, or fully 700 feet above sea level. The shale formation has a very uneven surface, and the ridges have been padded out with clay deposits. These were derived from the shale in large part, probably through the abrasion by the ice sheet, and yet they are often laminated as if deposited in water and are nearly free from stones such as appear in till. They are therefore considered lacustral rather than glacial deposits. They are overlain by till, and thus shown to be inter-Glacial. The lake clays are built up on some ridges to a height of nearly 300 feet above Lake Michigan, or much higher than the top of the shale ridges. The lake clays when not too thickly covered by

till deposits have been shaped into drumlin form. Throughout much of the district, however, the drumlins are composed wholly of till. This drumlin district and the finger lakes associated with it finds its southeastern border in a prominent moraine running from northeast to southwest across the southeastern part of Charlevoix and central part of Antrim counties. On the outer or southeastern border of this moraine is a gravel plain forming a well-defined line of glacial drainage utilized because of its smoothness by the Grand Rapids and Indiana Railway from Elmira southwestward to Kalkaska. East of this gravel plain is an abrupt rise of about 150 feet to another moraine and this has a gravel plain on its outer or southeastern face that covers the southeast part of Antrim County and embraces the source of Manistee River.

Striking differences in water supplies are found which are determined by the texture of the deposits and the topographic relations just outlined. In the gravel plains and also to a great extent in the moraines that lie southeast of the drumlin district the water table is found at a level as low as the neighboring lakes and streams, for there appears to be little or no clay above this level to prevent the water passing down.

On the high moraine east of the Grand Rapids and Indiana Railway, wells are accordingly sunk to a depth of about 200 feet, or to the level of lakes in the gravel plain along the railway. Wells are 50 to 75 feet or more in this gravel plain. In the moraine west of the railway some wells have been found at depths of 30 to 50 feet, but the best supply is generally found by sinking to depths of 150 feet or more to a level in accord with streams on the inner face of the moraine.

Upon entering the drumlin area the conditions become more complex, for there no general water table is struck either near the surface or at great depths. The lake clay as well as the till carries water only along certain favored courses where there are sandy partings or veins, and the position of these can not be predetermined. Neighboring wells may, therefore, differ very greatly in depth, one obtaining water at 20 feet or less and its neighbor going to depths of 100 or even 200 feet. Instances were found where wells on the crest of drumlins, standing nearly 100 feet above the bordering sags, have struck water at only 30 to 50 feet, while neighboring wells nearer the level of the sags have gone far below the level of the lowest ground in the vicinity before obtaining a good supply.

Along the borders of the system of finger lakes several small flowing-well districts have been developed as indicated below, but the wells seldom have such head as the great reliefs would lead one to expect, and the districts in which flows are obtainable seems to be restricted, like the supplies in the drumlin areas to favored localities.

valleys in which these lakes lie seem to be underlain by a looser ›d material than the lake clay. This is commonly termed ınd, but in the absence of samples it can not well be compared ıe lake clay exposed in the ridges. There is generally a coarse ›vering the valley bottoms, derived in part from hillside wash, full extent and relations are undetermined. Many wells in the are very shallow and obtain their supply from the coarse sand. rock formations furnish but a limited part of this district with the only points noted being a narrow strip along the border of lichigan from near Norwood to Petoskey and thence eastward he south side of Crooked Lake to Burt Lake.

FLOWING WELLS.

ing wells have been obtained from the rock near Norwood, and rlevoix, Petoskey, and Bay View, and possibly farther east in m Emmet County, as indicated in the report by Mr. Gregory 5–378). The flowing-well districts of Charlevoix and Antrim s have received only a hasty inspection by the writer in con- ı with other lines of investigation.

ALDEN.

n, a village on the east shore of Torch Lake, in Antrim County, ıllow wells on the shore of the lake with sufficient head to flow, mps are attached.

well, made by L. Armstrong at a feed mill, is only 12 feet deep, other, owned by Mr. Terrell, is of similar depth.

amin Armstrong has a well about 100 feet deep on higher in the eastern part of the village, the water in which stands the surface.

›ep boring was made north of the station in Alden by E. F. which struck water veins at 57, 68, and 86 feet depth. The rom the 68-foot vein rose to the surface at an altitude 10 feet Torch Lake, but from the other veins it fell short a few feet. ring was carried to a depth of 278 feet without reaching rock. largely through sand, with thin beds of hard clayey material, ›pth of 86 feet. The remainder of the section was nearly all ıough some beds of fine quicksand 2 to 8 feet thick were passed h. The lower 27 feet was a hard blue clay, and the boring d in this deposit.

INTERMEDIATE LAKE DISTRICT.

GENERAL RELATIONS.

g the border of Intermediate Lake, from Central Lake village ard past Bellaire, the county seat of Antrim County, flowing re obtained at several points. Some are very shallow and pen-

etrate little but muck and marl. Others go to considerable depth through clay before striking a flow. The wells are all on low ground bordering the lake or its outlet. Those at Central Lake are at an altitude of 609 feet above tide, or 2 to 7 feet above the lake, and those between Central Lake and Bellaire are at similar altitudes, with the exception of a well at a schoolhouse in the northeast corner of sec. 7, T. 30 N., R. 7 W., which is on ground about 640 feet above tide, or 33 feet above the lake. The waterworks wells in Bellaire are along the outlet of Intermediate Lake below the dam at an altitude of only 600 feet, and a well south of Bellaire, on the border of Goose Lake, is at similar altitude. On each side of Intermediate Lake a rapid rise is made to uplands standing 200 feet or more above the lake. The head in the wells is only a few feet above the surface, or less than might be expected from the height of the bordering uplands. The uplands have a large amount of inter-Glacial lake clay capped by only a few feet of glacial deposits. This clay is very slowly pervious to water and may not therefore contribute much water to increase the head in the wells along the lake.

BELLAIRE.

An examination of the several flowing wells of Bellaire was made by Hon. Roswell Leavitt, of that city, prior to the writer's visit, and the data here presented were mostly collected by him.

There are two flowing wells at the Bellaire waterworks, one being a large excavated well 60 feet in depth, the other a tubular well 6 inches in diameter and 55 feet in depth. The temperature of water from the tubular well is 47.8° F. The large well furnishes the main supply for the village, and water is pumped from it to a reservoir, which gives 72 pounds pressure at the level of the railroad station, 614 feet above tide. When the flowing wells prove inadequate, water is pumped from the mill race. This is at times very unsatisfactory, and many citizens depend upon private wells, in which water is obtained at depths of 14 to 35 feet. It is thought that a supply from Cedar River, which comes into the village from an elevated district on the east, would be preferable to the water from the mill race, now turned into the public supply, which carries much refuse from a mill that stands above the intake.

A flowing well was obtained on the property of G. J. Noteware on the site of an old sawmill, about 1½ miles south of Bellaire, at the east edge of Goose Lake, in the central part of sec. 31, T. 30 N., R. 7 W. The well had ceased flowing in 1904. The depth is about 28 feet, and it was made about 1890.

The schoolhouse well, in the northeast corner of sec. 7, T. 30 N., R. 7 W., was not flowing in October, 1904, but is reported to discharge a

nall stream from the pump spout in wet seasons. The depth is 47 et, and it was made about 1901.

On an island in Intermediate Lake in the southwestern part of sec. T. 30 N., R. 7 W. is a flowing well 28 feet deep made by S. Brodeay, which is used by summer visitors. No record was obtained, but is reported to have passed through marl.

Fisk Brothers have a camp and flowing well in sec. 1, T. 30 N., R. W. near the bank of Intermediate Lake and about 4 feet above ater level. It was driven to a depth of 67 feet through sand and ravel and a bed of clay. Water barely comes to the surface. It as made about 1902.

CENTRAL LAKE.

The strongest flow in the group in and near the village of Central ake is from the well of the Cameron Lumber Company, made in 902, which discharges 4 gallons a minute from an escape pipe threeourths of an inch in diameter, at an altitude of 10 feet above Intermediate Lake. The temperature was found to be 48° F., at a time hen the air was 60° F. and the lake 64° F. The temperature is said o be very uniform throughout the year and the flow steady. The vell penetrated the following deposits: Sand, 2 feet; marl, 20 feet; ellow clay, 200 feet; sand and gravel, 7 feet. Another flowing well ne-half mile south of the Cameron well at a camp of Fisk Brothers is nly 21 feet deep. The well passed through a few feet of marl and hen clay before striking water. Analyses of these two wells and of ne other follow, the data being furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters near Central Lake.

[Parts per million.]

	1.	2.	3.
lor	5	29	24
on (Fe)	Strong trace.	3	Strong trace.
lorine (Cl)	11.5	4	9.1
rbon dioxide (CO_2)	67.14	76.77	86.97
lphur trioxide (SO_3)	5	5	8
rdness (as $CaCO_3$)	139+	139+	139+

. J. Lewis, analyst. 1. Public supply (spring). 2. Cameron mill; depth 222 feet. 3. F. M. Fisk; pth, 36 feet.

Just north of Bridge street in Central Lake, on the west bank of the ke, are four shallow flowing wells, which have been in operation for veral years. Charles Briggs's well, made in 1897, is 27 feet deep, as 1¼-inch pipe, and flows 3 quarts a minute at a level 3½ feet above round, or 614 feet above tide. The water will rise to 616 feet. The mperature is 50° F., or somewhat above that usual in this latitude.

The well passed through considerable bog line but started and ended in sand.

About 50 yards north of the Briggs well is the well of S. Frost, 37 feet in depth with 1½-inch pipe and 1-inch escape. It flows 6 quarts a minute from a pipe 18 inches above the ground, or 610 feet above tide. The well has been running ten years.

Across the road from the Briggs well, on south side of Maple street, is the flowing well of Will Acker on ground 613 feet above tide. The well is 25 feet deep, and flows 5 quarts a minute from a pipe 15 inches above the surface. It flowed more rapidly when first made in 1896, and flows a little faster for two months in the spring. The well is 1¼ inches, but the escape pipe is three-fourths inch. The water will rise 3 feet above the top of the pipe or to 617 feet. Considerable yellow sand was penetrated, but there is some clay and some marl or bog lime. The temperature is 48° F. The water is hard, but does not show much iron.

South of the Acker well near Bridge street is Mrs. Hastings's flowing well, 20 feet in depth, on ground 611 feet above tide. The water issues from the pipe 3 feet above the surface at the rate of 4.5 quarts a minute and has a temperature of 50° F. The water is hard. This well was driven in 1902. There was one a few feet west of this from which the pipe has been drawn because the screen was worn out.

At the old stave-mill site in the north part of Central Lake was a flowing well 66 feet deep that used to flow from a vein 33 feet below surface. This was not visited as no use is now made of the water.

SUMMARY.

Wells of Intermediate Lake district.

Owner and location.	When made.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*	
Bellaire waterworks (2 wells)	.....	600	60 55	540 545	.....	.....	47.8	
G. J. Noteware, sec. 31, T. 30 N., R. 7 W.	1890	600	28	572	.....	.....	.....	
Schoolhouse, sec. 7, T. 30 N., R. 7 W.	1901	640	47	593	643	.....	.....	
Fisk camp, sec. 7, T. 30 N., R. 8 W.	1902	611	67	534	612	.....	.....	
S. Brodeway, sec. 7, T. 30 N., R. 7 W.	.....	609	28	581	612	.....	.....	
Cameron Lumber Co., Central Lake	1902	612	223	389	+617	16	48	See analysis (p. 337).
Fisk camp, south of Central Lake	.....	612	21	591	615	.....	.....	Do.
C. Briggs, Central Lake	1897	611	21	584	616	3	50	Hard.
S. Forest, Central Lake	1894	608	37	572	(?)	6	48	Do.
Will Acker, Central Lake	1896	613	25	588	616	5	48	Do.
Mrs. Hastings, Central Lake	1902	611	20	591	616	4.5	50	Do.

NORWOOD.

A flowing well 33 feet deep was made in 1866 at a mill in Norwood, the edge of Lake Michigan, which is still flowing 13 feet above ıke Michigan. The water is from gravel.

Another flowing well was obtained in rock in 1904, in a test boring miles south of Norwood. It struck the flow under shale at a depth 150 feet and it is reported to discharge a full 4-inch stream.[a]

The conditions seem favorable for obtaining flows at other points ›ng the shore, if on ground less than 15 feet above the lake. There ɜ numerous springs in the vicinity of Norwood, but they appear to ɜp from the hillside rather than boil up from the bed of gravel that ɜlds a flow.

EAST JORDAN-SOUTH ARM DISTRICT.

East Jordan stands at the head of the south arm of Pine Lake in uthern Charlevoix County. The valley in which the lake lies is ›out a mile wide. On each side is a rapid rise to uplands standing 0 feet or more above the lake. The wells are on low ground borderg the lake, some of them being in a marsh underlain by marl that is ›bably a filled portion of the lake.

There are nine flowing wells at the East Jordan waterworks, rangg in depth from 75 to 105 feet and having a diameter of 3 inches. ıey are all at an altitude of 585 feet and are confined to a space of 3 4 square rods, or not more than one-fortieth of an acre. They ve a slight head and a total discharge of 56,000 gallons a day. ee p. 346.)

At a shingle mill of the East Jordan Lumber Company, one-fourth le south from the waterworks, is a flowing well 50 feet deep, and ere are two others at dwellings near by on the mill property. The ;itude is about 585 feet. The well at the mill flows 15 quarts a nute through a 1-inch escape pipe, and has a temperature of 46° F. well at one of the residences has a flow of 7 quarts a minute, and a mperature of 46° F. The rate of flow of the third well could not be certained, as it escaped from a box. The mill well has been running out thirteen years, but those at the dwellings are more recent, one ing made in 1902.

On the north side of State street, at the drug store of L. C. Mattison, ere was a flowing well which became clogged and was abandoned. ıother well was then sunk to a depth of 70 feet that has a head of 1 ›t, but the pipe was not brought to a level low enough to allow it to w. This well passed through 30 feet of bog lime or marl and then ·ough fine sand, no clay being present.

A boring near the corner of State and Second streets, made by W. L. ench, was carried to a depth of 280 feet entirely through fine sand

[a] Data by William Harris, of Norwood.

with only an occasional fine pebble. The boring was abandoned without getting water, because of some difficulty in preventing sand from rising in the pipe. This boring serves to demonstrate the presence of a deep pre-Glacial valley under the lake, for it was driven to about 300 feet above tide without reaching rock.

George Japson has a well at the east end of the bridge that crosses the south end of the lake, which has a head 4 feet above the surface, but which is prevented from flowing by having the pump pipe carried up to a level above the head of the water. The well is about 45 feet in depth, with 1½-inch pipe, and was made in 1897.

J. H. Lamway, in the village of South Arm, across the lake from East Jordan, has a flowing well 48 feet deep and 1¼ inches in diameter. It stands at the edge of the lake and has a head 18 inches above lake level. The rate of flow is 10 quarts a minute. It seems to be very largely through muck and bog lime, but as the pipe was driven with a sledge there is very little knowledge of the material penetrated. The well was made in 1890 to a depth of 44 feet. It became clogged in 1898 and was then driven to 48 feet. The temperature is 48° F., or 2° higher than the East Jordan flows. An analysis of the water was made by Mr. Lewis. Mr. Lamway has two other wells, one at his barn and one at his store, each about 46 feet deep, that have a similar head to the flowing well by the lake, but being on higher ground they lack a few inches of reaching the surface. Other wells in the village when carried to depths of 40 feet or more show a rise nearly to the surface.

In the following table are given a number of partial analyses of water from Bellaire, South Arm, and East Jordan, including one from mill race leading from the river. The public supply at Bellaire is from a 60-foot flowing well; that of East Jordan from nine connected wells. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters from Bellaire, South Arm, and East Jordan.

[Parts per million.]

	1.	2.	3.	4.	5.
Color	24	19	19	5	5
Iron (Fe)	Strong trace.	Very slight trace.	Very slight trace.	0	Very minute trace.
Chlorine (Cl)	19.2	4	11.6	19.2	19.2
Carbon dioxide (CO_2)	72.99	65.96	66.2	66.18	71.23
Sulphur trioxide (SO_3)	0	5	5	0	0
Hardness (as $CaCO_3$)	139+	139+	139+	139+	139+

S. J. Lewis, analyst. 1. H. Richards, Bellaire; depth, 100 feet. 2. River (mill race), Bellaire. 3. Public supply (well), Bellaire; depth, 60 feet. 4. J. H. Lamway, South Arm; depth, 47 feet. 5. Public supply, East Jordan; depth, 75 feet.

IRONTON.

This village stands on the west shore of the south arm of Pine Lake about 6 miles southeast of Charlevoix. The land rises rapidly westward from the lake to a drumlin area whose highest points are abou

200 feet above lake level. On the slope wells have strong head when sunk to depths of 50 feet or more, but the shallow wells, 14 to 16 feet in depth, have but little head. There is a flowing well at Sequetata, a resort about a mile north of Ironton, at an altitude of 634 feet, or 54 feet above Pine Lake. It is 120 feet deep and passed through considerable red clay, probably inter-Glacial lake clay, before striking water. The water discharges at the rate of 2.4 quarts a minute at a level 2.5 feet above the surface. The temperature is 48.5° F. and the diameter of pipe 2 inches. The well was made in August, 1903.

About one-eighth mile west of this resort, on ground 31 feet higher, or 665 feet above tide, is a well at the residence of H. Coblentz, 50 feet in depth, in which water stands 1 foot below the surface. The diameter of the well is 3¼ inches. The water is very hard and has a temperature of 48.5° F.

There was a flowing well at Ironton, on the grounds of the Pine Lake Iron Company, which flowed a 1-inch stream for several years. It was made about twenty years ago, and is at an altitude of 605 feet above tide. The water now stands in the pipe about 1 foot above the level of the ground, but flowed over the top of the pipe 2 feet above the ground until 1903. When first made it would discharge from a pipe 4 feet above the surface. The depth is 130 feet, and water was found in sand below clay.

BOYNE.

This town stands at the east end of Pine Lake, an arm of Lake Michigan, which opens into the main lake at Charlevoix. Several flowing wells have been obtained at the shore of the lake about 5 feet above water level, and others up the valley of Boyne Creek. They are not from a single water bed, but strike water at various depths. The shallowest ones only pass through marl or bog lime that fills marshes along Boyne Creek valley, but the majority go through clay and find water in sand.

The strongest flow is one recently made (September, 1904) at the Elm Cooperage Company mill, in the eastern edge of town, nearly one-half mile from Pine Lake, but on the bank of Boyne Creek. The depth is 91 feet and the level of the discharge pipe 16 feet above Pine Lake, or 596 feet above sea level. It discharges a gallon in seven seconds from a ¾-inch nozzle, or at the rate of 7.5 gallons a minute. The discharge from the 2-inch pipe was much greater. The water will rise to 605 feet, or 25 feet above the lake level. The well passed through marl and sand for 40 feet, then through a stiff clay to the water-bearing gravel at about 90 feet. The temperature of the water is 46.5°, somewhat lower than that in wells of shallower depth and weaker flow tested on the same day. The water shows less iron than is commonly found in flowing wells, but is rather hard for boiler use

The cost of drilling this well was 45 cents a foot (driller, Willis Wilson).

There are several flowing wells at Van Platen's mill, on the shore of Pine Lake, with a depth of 63 to 65 feet. Only one is permitted to flow at present, and this discharges nearly 4 gallons a minute from a 1-inch pipe at 4 feet above the surface, or about 8 feet above the lake. The wells are 1½ inches in diameter. These wells are near the engine, and the water seems to be affected by the heat, for it showed a temperature of 50° F.

Across the street the engineer of this mill, James Smith, has a flowing well 78 feet in depth, with a temperature of 48° F. It flows only half a gallon a minute, and the water carries considerable iron as well as lime.

White's machine shop has a weak flowing well near the bank of Pine Lake, now clogged and out of use. It flows 3 quarts a minute and has a temperature of 49.5° F.

John Sudman has a flowing well on north side of Boyne Creek, about one-fourth mile from the lake, made in 1904, which obtained a flow from 47 feet depth. The water will rise 12 feet above the surface, or to 597 feet above tide, and discharges 1.5 gallons a minute from a 1½-inch pipe; temperature of water, 47.5° F.

There are two shallow wells across the creek from the cooperage mill, which strike flows under a bog-lime deposit at about 12 to 16 feet. Wm. Ormsley's well is 12 feet, has a head of 4 feet, and flows a gallon a minute. Its altitude is about 590 feet; temperature of water, 50.5° F. It has a slight taste of sulphur. Mr. Curtis has one 16 feet deep that brought up "snail shells" from the bottom.

Wells driven in the business part of Boyne to depths of 30 to 35 feet have a head very nearly level with the surface, which is 5 to 10 feet above the lake.

The two partial analyses from drift wells at Boyne are given below. The determinations, which were made by S. J. Lewis, were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Boyne.

[Parts per million.]

	1.	2.
Color	19	19
Iron (Fe)	Strong trace.	0
Chlorine (Cl)	14	4
Carbon dioxide (CO_2)	81.43	71.67
Sulphur trioxide (SO_3)	5	10
Hardness (as $CaCO_3$)	139+	139+

1. Cooperage mill; depth, 91 feet. 2. City; depth, 26 feet.

SPRINGWATER SIDING.

A single flowing well at Springwater siding on the Grand Rapids ıd Indiana Railroad just south of the Charlevoix and Antrim county ıe gives the name "Springwater" to the siding. The well was dug any years ago by L. Meaker, of Boyne Falls, who reports that for ł feet there was loose gravelly material, beneath which he found a ue clay, and after penetrating it a few feet struck the flow. It ›urs out over the top of the well and runs away as a small brook. he temperature is 46.5° F. The well is in a deep valley with borderg hills fully 200 feet higher near by on the east, which may easily rve as a catchment area and give the head.

The valley leading from this siding down to Boyne Falls has springs ong its borders and bottom, which are probably fed from the water ›sorbed by the bordering hills. On the Robbins's farm, about midıy between Springwater siding and Boyne Falls, two wells 36 and 48 ɜt in depth have water only 10 to 15 feet below the surface. They netrated no clay, but are in sand and gravel from top to bottom.

BOYNE FALLS.

The village of Boyne Falls is in a valley bordered closely on the st by high land, the situation being similar to that at Springwater ling, but no flows have been obtained. A test boring was made out 1900 to a depth of nearly 300 feet on the McMahon property, e block north of the railroad station. There was some water at out 30 feet and at various lower depths, but the greatest head obined was 30 feet below the surface. There is a large amount of ter-Glacial lake clay in the highlands near this village which will not ›sorb water readily, and this may account for the failure to get flowg wells. Other tests, however, may result more successfully.

About 2½ miles northeast of Boyne Falls, on the farm of John Harɔn, is a well which when first made did not flow. But after the ımp was attached the water burst in with greater head, causing the ›ll to discharge through the pump spout a stream about one-half ɜh in diameter. This well was not visited, but was reported by L. ɜaker to be in a depression among hills.

WALLOON LAKE DISTRICT.

A well is reported to flow on the Rokopf farm on the west arm of alloon Lake, but was not visited.

At the outlet of Walloon Lake a well 175 feet deep is reported to ve flowed until it became clogged because of imperfect casing. ıis well is thought to have entered a gray shale at about 100 feet.

There was a flowing well at the tie mill by Bear Creek at Clarion, .t it has been out of use for some years, and appears to have stopped

flowing, though the writer did not visit the spot to ascertain the present condition.

These wells are all located in valleys bordered by prominent drift ridges and are of value in showing the promising prospects for development of a flowing-well district in the valleys.

WATERWORKS.

ANTRIM COUNTY.

Waterworks plants are in operation at Bellaire, Central Lake, Elk Rapids, and Mancelona, all of which use surface water except Mancelona, though Bellaire is supplied in part by flowing wells (see pp. 336, 345).

CENTRAL LAKE.

The public supply for Central Lake village is obtained from springs that issue on the slope west of the village at an altitude about 100 feet above the main part of town, as estimated by the reservoir pressure of 45 pounds. The springs yield 2,000 gallons an hour. The water runs from the reservoir through a pipe only 3 inches in diameter, but this is adequate to carry the water needed by the village for domestic use. The character of the water is shown by the analysis made by S. J. Lewis (p. 337). The waterworks plant is owned by private individuals, but the village is arranging for its purchase at an early date.

The springs do not boil up from deep strata like the flowing wells, but issue at the outcrop of nearly horizontal beds of sand which occur between beds of inter-Glacial lake clay.

ELK RAPIDS.

The waterworks are in the hands of a private company. The supply is derived from Elk Lake, being pumped direct to mains with an ordinary pressure of 45 pounds and a fire pressure of 100 pounds. Water power is used to run the pumps. The plant was installed in 1892.[a]

Private wells, which are in common use, are driven to the bottom of the sand at 20 to 25 feet. A boring 526 feet deep made by William H. Davis obtained a flow of water which is not utilized. The drift here is 475 feet, largely of blue clay said to be free from grit or pebbles.

MANCELONA.

The wells at Mancelona are sunk in the bottom of a natural basin about 40 feet below the general level of the town, and thus save the pipe necessary to reach water. The deposits penetrated are gravelly and the wells are cased to the water bed. Water is pumped direct to the mains.

---

[a] Manual of American Waterworks

MISCELLANEOUS SUPPLIES.

The principal data on village supplies of all sorts are embraced in e following table:

Village supplies in Antrim County.

Town.	Population (1900).	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to main supply.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
ba	600±	1,171	Driven wells	75	125	100	100	− 70 − 90	Strong west of Alba.
den	500±	603	Driven wells, Torch Lake.	10	278	15	15	+ 2 − 8	Small.
ıtrim		1,115	Tubular wells	70	300	70	70	− 65	Weak.
:wood		825	do	65	150	Variable.	Variable.	− 60 −135	Do.
'llaire	1,157	600 614	Driven wells, and stream by waterworks.	16	115	16–35	100	+ 3	Strong.
ntral Lake.	1,301	610 680	Springs by waterworks, flowing wells, lake.	12	230			− 6 + 3	Very strong, supplying waterworks.
ıestonia		650	Driven wells	10	20	20	20	− 10	Strong.
ıstport		600	Driven wells, Torch Lake.	15	25	20	20	− 10	Weak.
:ho		620	Stream and lake, flowing wells.						Strong.
llsworth	350±	610 650	Driven wells, springs, lake.	15	60	45	45		Small.
k Rapids	2,209	595	Elk Lake by waterworks, driven wells.	8	[a]526 186	20	20	− 16	None.
mira	300±	1,233	Driven wells	75	75	75	75	− 50	Weak.
nkton		750	do	50	100	50	50	− 30	Do.
ıncelona	1,226	1,117	Tubular wells by waterworks, driven wells.	40	125	65	65	− 32 − 50	None.
nons	300	1,197	Driven wells	100	100	100	100	+ 4? − 96	Small.
rch Lake		600	Driven wells, Torch Lake.	15	30	20	20	− 10	Do.

[a] Test well.

CHARLEVOIX COUNTY.

Waterworks have been installed in Bay Shore, Boyne, Charlevoix, ıd East Jordan.

BAY SHORE.

The supply at Bay Shore is pumped from Lake Michigan to an eleted tank. It serves mainly for fire protection, private wells being e main domestic supply.

BOYNE.

The public supply is from springs that issue at the base of prominıt hills on the south border of the town. The springs are in a marl l under a foot or two of peat. The water, as may be expected, is rd and contains iron. It is collected under a shed which protects from leaves and floating refuse matter, and flows by gravity to a ervoir 67 feet above the level of Pine Lake, giving it all the pressure ailable at *present*.

CHARLEVOIX.

At Charlevoix water is obtained from Lake Michigan, a filtration gallery being used. This village sunk three deep wells some years ago for the purpose of obtaining a supply, but this proved unsatisfactory and the present supply was recently adopted. Water is pumped direct to the mains, with an ordinary pressure of 50 pounds and fire pressure of 100 pounds or more.

EAST JORDAN.

The supply at East Jordan is from nine flowing wells, as indicated on pages 339–340. The flow of these wells, amounting to 56,000 gallons a day, is not enough to meet the demands of the town, and pumps have been installed which draw about 300,000 gallons a day in the dry portion of the summer. The water is pumped to an elevated tank 20 by 20 by 24 feet, standing on a tower at sufficient height to give 80 pounds pressure at lake level. It has a temperature of 46° as it flows from the wells. The first wells were made in 1897, but some are as recent as 1901. An analysis is given in the table on page 340.

MISCELLANEOUS SUPPLIES.

The principal data on village supplies are embraced in the following table:

Village supplies in Charlevoix County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs.
		Feet.		*Feet.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Feet.*	
Advance	100±	600	Wells, lake and springs.	40	6	40	10	30	− 5	Large.
Bay Shore	350±	625	Lake Michigan by waterworks, open and driven wells.	15	20	100	40	40	.....	Small.
Boyne	[a]2,453	590	Springs by waterworks, driven wells, some flowing.	.....	10	90	20	20	+ 5	Large.
Boyne Falls	431	711	Driven wells	.....	14	120	25	25	−20	Small.
Charlevoix	2,079	590 620	Lake Michigan by waterworks, driven wells.	15 230	25	482	50	50	+ 5 −30	[illegible]
Clarion	200±	685	Wells and springs	.....	10	30	25	25	.....	[illegible]
East Jordan	1,205	590 600	Flowing wells by waterworks, wells and springs.	280+	25	280	25	75	+ 5	Large.
Horton Bay	.....	600	Wells and springs	.....	17	17	.....	.....	−15	Do.
Ironton	.....	600	Wells and Pine Lake	.....	14	60	.....	.....	+ 1	Do.
Norwood	150±	595 660	Wells and Lake Michigan.	.....	20	175	60	60	+ 5 −30	Do.
Phelps	.....	700±	Open wells	.....	8	30	10	10	− 4	Small
St. James (on Beaver Island).	500±	600	Driven wells, Lake Michigan.	.....	12	35	25	25	.....	
Springvale	.....	950	Driven wells	.....	65	100	65	....	−30	None.
Thumb Lake	.....	1,100+	Driven wells, lake	.....	37	70	65	65	−40	Large.

[a] In 1904.

WATER SUPPLIES OF OTSEGO COUNTY.

By Frank Leverett.

'eneral statement.—Otsego County, of which Gaylord is the county t, is one of the most elevated counties in the north end of the ıthern Peninsula and contains the headwaters of Au Sable, Man- 'e, and Cheboygan rivers. Its western edge was covered by the ke Michigan lobe, but the remainder of the county by ice pushing thwestward from the north end of Lake Huron. There is an erlobate moraine in the southern part of the county, with Otsego ke lying in the midst. The portion of the moraine west of the lake he product of the Lake Michigan ice lobe, while that on the east s formed by ice from the Lake Huron basin. To the north and st of this interlobate tract is an extensive gravel plain standing in reentrant angle between the two ice lobes. Its altitude at the 'thern edge is 1,350 to 1,400 feet above the sea, or nearly as high as crest of the moraines which sweep around it on the east, north, and st. The city of Gaylord stands on this gravel plain. The portion the county northeast of Gaylord is all morainic, but among the raines there are numerous channels apparently formed by glacial ters as the ice was shrinking down the slope toward Lake Huron. is part of the county is drained northward to Cheboygan River ough Pigeon and Sturgeon rivers. The southern part is drained to Au Sable, which flows eastward to Lake Huron, while the western ge is drained by the Manistee, which leads westward into Lake chigan.

The drift is probably several hundred feet in thickness except, per- ps, in the northeastern part. Rock in this part of the State is not own to occur at an altitude greater than 900 feet, and the surface of s county would average about 1,200 feet.

Wells.—Wells on the elevated tracts 1,350 to 1,450 feet above tide 100 to 325 feet in depth, the deepest well reported being in Dover wnship, a few miles northeast of Gaylord. Two wells on the moraine itheast of Otsego Lake, at an altitude of 1,375 to 1,400 feet, are h 175 feet deep and have only a few feet of water in the bottom. lls on the high moraine east and south of Elmira are from 130 to feet in depth. On the high moraine west of Vanderbilt, John rner has a well 275 feet in depth, on ground about 1,350 feet above , in which there is only 30 feet of water; after penetrating 20 feet of face till, this well was mainly in dry gravel and sand to the water bed about 270 feet. On the gravel plain in the reentrant angle between Lake Michigan and Lake Huron moraines, northwest of Gaylord, eral wells are 160 to 175 feet in depth, the altitude being about 30 feet. South from these wells, on ground about 1,325 feet above , are wells 100 to 120 feet in depth which have scarcely 20 feet of

water. At Gaylord, at an altitude of about 1,340 feet, the usual depth of wells is 80 feet, and wells are 80 to 120 feet from Gaylord eastward past Johannesburg. Around Otsego Lake the wells are much shallower, the range being from 18 to 45 feet, but the altitude there is a little less than 1,300 feet. Wells are also obtained at depths of 40 to 50 feet in a belt running northwest from Otsego Lake to the edge of Elmira Township. Around Vanderbilt the wells are only 40 feet and strike water at 30 feet; but this town is on a gravel plain much lower than that at Gaylord, the railroad station being 1,090 feet. On the moraine north of Vanderbilt, near the line of Otsego and Cheboygan counties, at an altitude of 1,175 feet, several wells are about 180 feet in depth.

The following communication from Mr. J. B. F. Gocha, an experienced well driller at Gaylord, gives the results of a season's drilling in 1901 in that region, and notes concerning the deepest well yet reported. All are tubular wells except one in Livingston Township, which was driven.

Wells in Otsego County and vicinity.

Township.	County.	Diameter.	Depth.
		Inches.	*Feet.*
Hayes	Otsego	2	112
Star	Antrim	2	150
Bagley	Otsego	2	82
Do	do	2	50
Gaylord	do	2	100
Do	do	2	98
Bagley	do	2	91
Corwith	do	2	92
Hayes	do	2	75
Livingston	do	1¼	30
Do	do	2	117
Gaylord	do	2	105
Hudson	Charlevoix	2	[illegible]
Wilson	do	2	[illegible]
Charlton	Otsego	2	[illegible]
Dover	do	2	[illegible]
Bagley	do	2	[illegible]
Do	do	2	[illegible]
Hayes	do	2	211
Do	do	2	110

Mr. Gocha says:

The soil in these wells is mostly plaster sand, with some gravel and cobblestone and hard-head stone and some clay, but not much. These wells were all made with No. 60 gauze points or screens, with Eureka brass cylinders and Maud S. pumps. The water does not rise at all and you have to case every foot of it [the well]. In my 325-foot well in Dover Township I had to dig down 223 feet and put in a 4-inch casing 7 feet long to keep the sand and water from holding my 2-inch casing in about 7 feet of clay. There was 3 feet of water on the clay. The well is now in good running order, and I am going to put in a 10-foot Fairbanks windmill to pump the water. The water is hard. It is for farm use.

Springs.—Springs of considerable strength are found along the borders of the streams, but hillside springs are exceedingly rare, since the water table under the hills is nearly as low as in the surface of the streams.

Waterworks.—The public supply of Gaylord is from a well 80 feet ep, from which water is pumped to a standpipe. The well pene- ıted gravel for its entire depth and came into water near the bottom, e general level of the water table being nearly 80 feet below the sur- ce. Many of the residents depend on private wells, though the pub- ; water supply is considered of good quality.

WATER SUPPLIES OF MONTMORENCY COUNTY.

By Frank Leverett.

Montmorency County lies east of Otsego County. The large orainic belt of northeastern Otsego runs southeastward across it, vering much of the central and southwestern parts. The south- est corner is on an elevated gravel plain. The northern and eastern ırts of the county are largely sandy plains, in which there are small kes and swampy areas, some being of considerable extent. These ains extend southwestward into the high moraine in recesses com- arable to the finger-lake tracts of the Lake Michigan slope in Antrim nd Charlevoix counties (pp. 333–334), but have only a small part cov- red with lakes. The prominences between them are morainic and ot shaped into drumlin form, as they are in Antrim and Charlevoix ounties. The entire drainage is tributary to Lake Huron, but rains in various directions. The northwestern part of the county is rained northward by Black River to the Cheboygan; the southwest- rn corner southward to the Au Sable, and the remainder and greater art eastward by various tributaries of Thunder Bay River to the ıke at Alpena. Each stream is bordered by broad sandy tracts long much of its course. Most of the streams originate in springs, nd there is a large amount of seepage into them from the bordering 'ains. A spring a few miles northeast of Atlanta is reported to dis- ıarge a large amount of inflammable gas, but it was not visited by e writer.

There are few settlers except in or near Vienna and Lewiston in the uthwestern part, Atlanta (the county seat) in the central part, and illman in the eastern part of the county; the entire pouplation in 00 was only 3,234. The main farming settlements are within a few les north and south of Hillman, where the soil carries a consider- le amount of clay both on the moraines and plains. There are also ıumber of good farms in the southwestern fourth of the county, ıefly on the elevated moraine and the gravel plain outside of it.

In this county, as in Otsego, wells generally need to penetrate to out the level of the base of the morainic ridges to find adequate plies. At Lewiston, which is built on the borders of Twin Lakes, wells are shallow, although the altitude is high. At Vienna, and st from there in the moraine, the wells usually reach depths of 100

feet or more. Atlanta is in a plain near Thunder Bay River and has shallow wells, and Hillman (also on this plain) has wells of moderate depth. The neighboring farming districts, also being largely on ground but little above the river, have shallow wells. Lewiston has waterworks used chiefly for fire protection and supplied from Twin Lakes. Hillman has a plant for fire protection supplied from Thunder Bay River. Atlanta is planning for a plant for fire protection supplied by Thunder Bay River.

The principal data on wells in and near the villages are included in the following table:

Village supplies in Montmorency County.

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Atlanta	900	Driven wells	14	24	22	22	−15	Large.
Big Rock	950	Driven wells, lakes	10	65	30	50	−30	Do.
Hillman	800	Thunder Bay River, by waterworks, open and driven wells.	25	150	50	75	−30	Small.
Lewiston	1,200	Lakes, by waterworks, driven wells.	22	36	30	25	−22	
Valentine Lake	950	Driven wells	30	217	45	45	.....	Large.
Vienna	1,300	.....do	50	140	110	110	−50	Small.

WATER SUPPLIES OF ALPENA COUNTY.

By Frank Leverett.

Alpena County fronts on Lake Huron in the northeastern part of the Southern Peninsula, the county seat being the city of Alpena. It is all within the drainage basin of Thunder Bay River except a narrow strip next to Lake Huron. The southwestern part is elevated like the adjoining parts of Montmorency and Alcona counties, with ridges rising to nearly 1,200 feet, and has very few settlers. The remainder of the county is comparatively low, most of it being between 700 and 900 feet above tide. There are a few square miles of barren sand along the shore of Lake Huron west and south of Alpena and a swamp in the northwestern part of the county occupying several square miles. With these exceptions and counting out the elevated tracts in the southwest, the county is well adapted for farming and is already largely under cultivation. In the northern half, rock is near the surface, and in a limestone district which runs from Alpena northwestward the bed rock is often exposed in roadside ditches and forms a low cliff south of Long Lake. Sink holes abound from near Flanders, northward past Long Rapids, into Presque Isle County. The north branch of Thunder Bay River, when the country was first settled, had its entire low-water flow absorbed by a sink hole at the

of its valley near the line of Presque Isle and Alpena counties, a dam has now been constructed which prevents it from entering.

n the limestone district in the northern part of the county the th of wells varies greatly because of the different levels at which er is found in the rock. This seems to be completely filled with er only to a level a little above Lake Huron; but there are in es higher shale beds that prevent the water from going directly n to this low-water table, and in such places wells can usually be l at moderate depth, though even in these places they often reach ths of 50 to 100 feet. The water is usually of good quality for king, though very hard.

n the southern half of the county, where the wells draw their sup- from the drift, the depth ranges from 20 feet to about 120 feet, deepest wells being on the ridges.

t Alpena there are several deep wells which obtain a large supply lowing water from 600 to 650 feet, some of the wells being carried much greater depths. The water is reported to rise to about 40 above Lake Huron. It is sulphated and sulphureted, but is not y salt and can be drunk without much discomfort. The tempera- of a well at the office of the Fletcher Paper Company was 53.5° August 8, 1905. Analyses appear in Water-Supply Paper No. 31, es 72 and 73.

prings are not so conspicuous in this county as in the higher nties to the south and west, but there are weak ones along the er courses at numerous points.

he city of Alpena purchased in 1905 the old plant of a private er company installed in 1879, which, it is reported, has a consid- ble extent of wooden mains and is generally run down. It is posed to use this only until a new plant can be installed. The ply is drawn from Thunder Bay and pumped direct to the mains.

he principal data concerning the supplies at the several villages in vicinity of country post-offices are presented in the following le:

Village supplies in Alpena County.

own.	Elevation.	Source.	Depth to rock.	Depth of wells. From-	To -	Common.	Depth to main supply.
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
a	585-610	Thunder Bay, deep and shallow wells.	0-80	20	1,278	640	620
n	730	Open and drilled wells	0-20	10	100	50	50-100
o	725	do	5-20	8	100	75	50-100
era	760-800	do	50-80	20	80	Variable	Variable.
ard Lake	725	do		20	120	do	Do.
Rapids	725-825	do	0-20	20	60	60	60
ke	604	Devil River, springs, no wells.					

WATER SUPPLIES OF PRESQUE ISLE COUNTY.

By Frank Leverett.

General statement.—Presque Isle County has an extensive frontage on Lake Huron above Alpena County, and its county seat, Rogers, stands on the lake shore. The greater part of the county has limestone at slight depth. The southwest corner, a morainic tract in Moltke Township west of Rogers, and another in the northwest part of the county, are the only districts in the county where the drift deposits are so thick as to supply wells and leave the distance to rock uncertain. A chain of sink holes in the southwest corner is thought to indicate that limestone immediately underlies the drift there, and if so the entire county has a limestone platform beneath the drift, except at the outcrops of the narrow strips of shale that occur between the limestones. Low escarpments face northeast near Ocqueoc and south of Rogers, continuing southeastward into Alpena County. Grand Lake and Long Lake in the eastern part of the county lie at the base of such limestone cliffs.

Part of the southern side of the county drains into the north fork of Thunder Bay River and thence southward. The southwest part drains northwestward, through Rainy and Black rivers, to Cheboygan River. A narrow belt along the lake front drains more directly to Lake Huron through several small streams.

Wells.—The best supplies of water in the limestone are found at levels nearly as low as the surface of Lake Huron. This is well shown at Onaway, where the largest supplies are from 250 feet, and also at numerous farm wells in the central and eastern parts of the county. In the villages the wells are usually of less depth, drawing on weak surface veins. No deep wells have been made in the region of heavy drift in the southwestern part of the county, where there are very few settlers. The belt of heavy drift in Moltke Township is thickly settled and has some deep wells, several being over 100 feet, and one, that of F. Sargenfrei, in sec. 23, being 260 feet. The Sargenfrei well is about 270 feet above the surface of Lake Huron, and is thought to have struck rock at bottom. The other wells are at about the same altitude and have not reached rock. At Rogers there is a gap in the limestone bluff filled in by drift to a level 50 to 80 feet below Lake Huron, and in this flowing wells may be obtained, as indicated below.

Flowing wells can probably be obtained only on low ground near the shore of Lake Huron. A flowing well has been obtained at a gristmill at Rogers by penetrating to a depth of about 100 feet. It struck water in gravel and has a head 15 feet above the surface and about 30 feet above Lake Huron. The well is 6 inches in diameter and flows 2 barrels a minute.[a]

[a] Reported by W. F. Cooper.

'erworks.—The waterworks plant at Onaway in the western part county is supplied by two wells 190 and 235 feet deep, which rock near the surface and are largely through limestone. The is pumped to a reservoir on a hill in the south part of town, ng nearly 100 feet above the railway station. The waterworks ; is in general use for domestic and manufacturing purposes, as ; for fire protection and sprinkling. The average daily consump- ı about 60,000 gallons.[a]

:cellaneous village supplies.—The principal data on supplies at ;s and in the vicinity of country post-offices are presented in llowing table:

Village supplies of Presque Isle County.

'n.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	To—	Common—	Depth to water bed.	Head.	Springs.
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
.....	600	Lake Huron, wells.....	.....	.....	10	8	.....	.....	Small.
ille ...	775	Wells.....	50	30	60	35	35	—25	Strong.
or Le e.	815	Open and driven wells.....	15	8	38	20	.....	— 5	Small.
ırg....	785	Wells and stream.....	.....	12	40	20	20	— 8	Do.
.....	800	Open wells.....	.....	.....	.....	.....	.....	.....	
.....	830	Drilled wells.....	5	30	600	200	250	.....	Do.
.....	788	Drilled and open wells.....	38	15	38	38	.....	—11	None.
.....	600	Open and driven wells, lake	60 100	17	165	22	.....	+15	

WATER SUPPLIES OF CHEBOYGAN COUNTY.

By FRANK LEVERETT.

GENERAL STATEMENT.

boygan County fronts on Lake Huron immediately east of the ; of Mackinac. It is comparatively low along the lake shore, ; northern half has only a few square miles higher than 200 feet lake level. Except for a few islands this part was once covered ke Algonquin. It contains four inland lakes—Douglas, Burt, ;, and Black—each with an area of several square miles, and ;l smaller lakes. Its southern half is largely morainic and ;s altitudes of 1,000 to 1,200 feet on the south border.

h of the streams running northward through the southern half county flows through valleys or plains 1 to 3 miles wide, above the moraines rise to heights of 200 feet or more. The eastern ; the county is largely unsettled except in a strip running south- ırd from Cheboygan past Black Lake to Onaway, and much of ıutheast quarter is still covered by hard-wood forests. The ;n half is largely cleared and much of it is settled.

[a] Data by W. Barker, superintendent of waterworks.

Limestone, with altitudes ranging from 350 feet below to 250 feet or more above Lake Huron, immediately underlies the drift of Cheboygan County and extends nearly to the southern end of the county. It is, however, covered thickly with drift in the southern townships and also from Mullet and Burt lakes southward, and is seldom reached by shallow wells in the north. At Cheboygan, the bed of a pre-Glacial valley 350 feet below the level of Lake Huron is reached by borings, and it is probable that this valley underlies Mullet Lake and comes in from the south past Wolverine along or near Sturgeon River Valley, for a boring at Wolverine about 300 feet deep did not reach rock.

In the settlements made on the moraines in the southwestern part of the county and in a rolling tract north and east of Douglas and Burt lakes, wells are generally sunk to the level of neighboring valleys or plains or to depths ranging from 50 to 250 feet or more In the valleys of the south, and in the bed of Lake Algonquin in the north part, wells are usually obtained at shallow depths unless flowing wells are desired. These are usually 100 feet or more in depth even when on ground but little above the inland lakes.

The conditions are favorable for obtaining flowing wells around the south end of Burt Lake, and along the western border of Mullets Lake, and to some distance southward along valleys that drain into these lakes. It is probable also that flowing wells could be obtained at moderate depths along Black River as far up as Black Lake, and perhaps along the part of the stream above the lake, as far as settlements have reached. But this valley has not as yet been tested sufficiently to determine the artesian prospects. There are also swampy tracts along the northern side of uplands southwest and west of Cheboygan, in which flows may be expected if borings are carried to moderate depths, for the wells on these uplands have a head somewhat above the swamps, beneath which the underground drainage is likely to pass on its way to Lake Huron. The principal development of flowing wells has been at Indian River and other points at the south end of Burt Lake, and along the west side of Mullet Lake.

SPRINGS.

At the south edge of a narrow ridge that lies between Douglas and Burt lakes is a spring that is thought to be the largest in the Southern Peninsula of Michigan. It emerges from the ridge as a torrent about 36 feet wide and 6 to 18 inches deep, which rushes down to Burt Lake with a fall of about 25 feet in a distance of perhaps one-half mile. The spring at its point of emergence is about 75 feet lower than Douglas Lake, and only one-half mile distant, and is thought to be fed by the waters of that lake. After leaving the field the writer learned that there is a whirlpool near an island in Douglas Lake which marks

› probable intake of the lake water. The temperature of the spring October 29, 1904, was found to be 50° F., which is about 4° higher ın the temperature of flowing wells in that region, and in harmony th shallow wells supplied with surface water, and whose tempera- re at that time of the year is about at its maximum. Possibly a ɔre careful investigation would fully settle the question of the rela- ɔn of this spring to Douglas Lake. Easily recognized objects or bstances if thrown into the whirlpool in the lake might be detected the spring and perhaps the rate of flow from the lake to the spring termined.

WATERWORKS.

CHEBOYGAN.

The waterworks plant is supplied from drilled wells 408 feet in pth which would flow if permitted, but is provided with an air lift order to increase the yield. The temperature is 51.8° F., or about higher than from the shallow flowing wells of that region.[a]

The wells penetrated about 360 feet of drift of which the upper part a depth of 150 feet is largely clay, but the remainder is nearly all nd. The wells terminate in dolomitic limestone, of the Monroe oup. The record of a deep boring at Cheboygan (2,750 feet), made test prospects for oil and gas, appears in the report of the State ologist for 1901, pages 230–231.

MISCELLANEOUS VILLAGE SUPPLIES.

At Freedom, on the shore of Lake Huron, wells are driven to depths 30 to 50 feet, or about to the level of Lake Huron.

At Mullet Lake and Indian River the main supplies are from wing wells, which are discussed below.

At Rondo, Wolverine, and Trowbridge, in the valley of Sturgeon ver, water is usually found at depths of 25 to 75 feet and on the ' bottom lands at less than 25 feet. An oil boring at Wolverine ground 62 feet above the railway station, or 835 feet above tide, s abandoned at about 300 feet without reaching rock. It found a ge amount of water, but the pressure was not sufficient for a flow.

FLOWING WELLS.[b]

MULLET LAKE.[c]

A flowing well some 2 or 3 miles back from Mullet Lake on the m of George Long, sec. 1, T. 36 N., R. 2 W., suggests the possi- ity of a large extension of the flowing-well district to the west from northern part of Mullet Lake, but this is at present the only well k from the immediate lake border. The Long well was visited

[a] Data from A. C. Lane. [b] By W. M. Gregory. [c] By Frank Leverett.

by the writer in October, 1904, and found to have an altitude about 60 feet above Mullet Lake, or 650 feet above tide, and to be bordered on the southwest by a range of hills 100 feet higher. Its depth is 97 feet, its head 26 feet, and its flow 2 gallons a minute through a 1-inch pipe. The temperature October 26, 1904, was 46° F. The well passed through 30 feet of hard clay just before striking the water-bearing gravel at bottom of well.

HAAKWOOD.[a]

At Haakwood station on the Michigan Central Railroad about 7 miles south of Indian River in the Sturgeon River Valley is a strong flowing well made by the Haak Lumber Company. The depth is 205 feet, diameter 3.5 inches, and flow about 9 gallons a minute. The well penetrated surface sand for 100 feet, then clay for 100 feet, and obtained water from gravel at bottom. The water will run from the top of a pipe extending 18 to 20 feet above the surface of the ground, but how much higher it will rise it has not been ascertained. The water is distributed as follows: One main about 300 feet long to barn; another about 1,200 feet long to the sawmill, and also 1,200 feet to some tenement houses. There are nine taps with nozzles that reduce the flow at each tap to a small stream that runs constantly.

The following analysis of this flowing-well water was made at Saginaw by H. and W. Heim, analytical chemists, September 11, 1900:

Analysis of water of Haakwood well.[b]

	Parts per million.
Total residue	297.5
Total mineral residue	227.5
Hardness	185.72
Permanent hardness	42.86
Silica (SiO_2)	5.50
Iron and alumina (Fe_2O_3, Al_2O_3)	37
Calcium (Ca)	60.01
Magnesium (Mg)	10.03
Sulphate radicle (SO_4)	12.35
Carbonate radicle (CO_3)	86.91
Chlorine (Cl)	Trace.
Nitrates and nitrites	None.
	211.80

No other wells have been drilled at this point to sufficient depth to reach this water bed. The valley is bordered by high morainic

[a] Data by Haak Lumber Company.

[b] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

hills on either side, which probably serve as a catchment area, and flows should be obtained in it wherever the water beds are confined by clay, as in this well.

CHEBOYGAN.

In the city of Cheboygan good flows were formerly obtained at depths of 20 to 100 feet in a strip of land bordering Cheboygan River. Mr. Spiller, a retired well driller, says that a number of wells drilled by him twenty to twenty-five years ago gave strong flows at that time, although at present the water in them stands at nearly the same level as in the river. Messrs. Robert Patterson, Harris Embry, Withnow, and Brenton, all neighbors of Mr. Spiller, have wells at 60, 30, 19, and 25 feet deep, respectively. These all formerly flowed, but now the water level is 15 to 20 feet below the surface. The cause of the decrease in head is thought to be due to dredging a 10-foot channel in the river. Mr. Spiller observed that during the blasting for the removal of some of the large bowlders all the wells of his neighborhood ceased to flow. At the tannery of the Northern Extract Company several flowing wells were used for a few years, but at the present time a flowing well 6 inches in diameter and 629 feet deep furnishes an abundant supply of a hard alkaline water. There are several other deep wells in Cheboygan. Three are owned by the Fletcher Paper Company and one by C. Moench Sons Company. The city waterworks are supplied by a flowing well 408 feet deep, which, according to Dr. A. C. Lane, has a temperature of 51.8° F.[a]

INDIAN RIVER AREA.

The artesian wells of Indian River are within an area of 2 square miles at the outlet of Burt Lake. The wells are on a low sand plain between higher tracts to the north and south of the village. The elevation of the well district varies from 600 to 640 feet above tide (see fig. 65, next page), while the catchment area to the south attains, within 8 or 10 miles, an altitude of more than 1,000 feet.

The wells of Indian River belong to a general belt which extends from Harbor Springs to Cheboygan, as outlined in the Harbor Springs discussion (pp. 366–370), and it is probable that flows may be obtained from Indian River all along the south and east shore of Burt Lake and the marsh that connects Crooked Lake with Burt Lake.

In the limits of the Indian River area 43 flowing wells have been made, and at the date of observation (August, 1904) 40 were in operation. In this village the first well was made in 1889 by George Patterson, and has been flowing with no apparent decrease in volume since drilling. The wells in the village are used entirely for domestic and laundry purposes, while at the summer resort of Columbus Beach

[a] Geol. Survey of Michigan, Ann. Rept. for 1901, pp. 230, 248, 249.

the purity and abundance of the water are attractions for summer homes. The summer population at Columbus Beach is supplied from 17 wells, the abundance and pressure of the water being such that some places have bathrooms on the second floor.

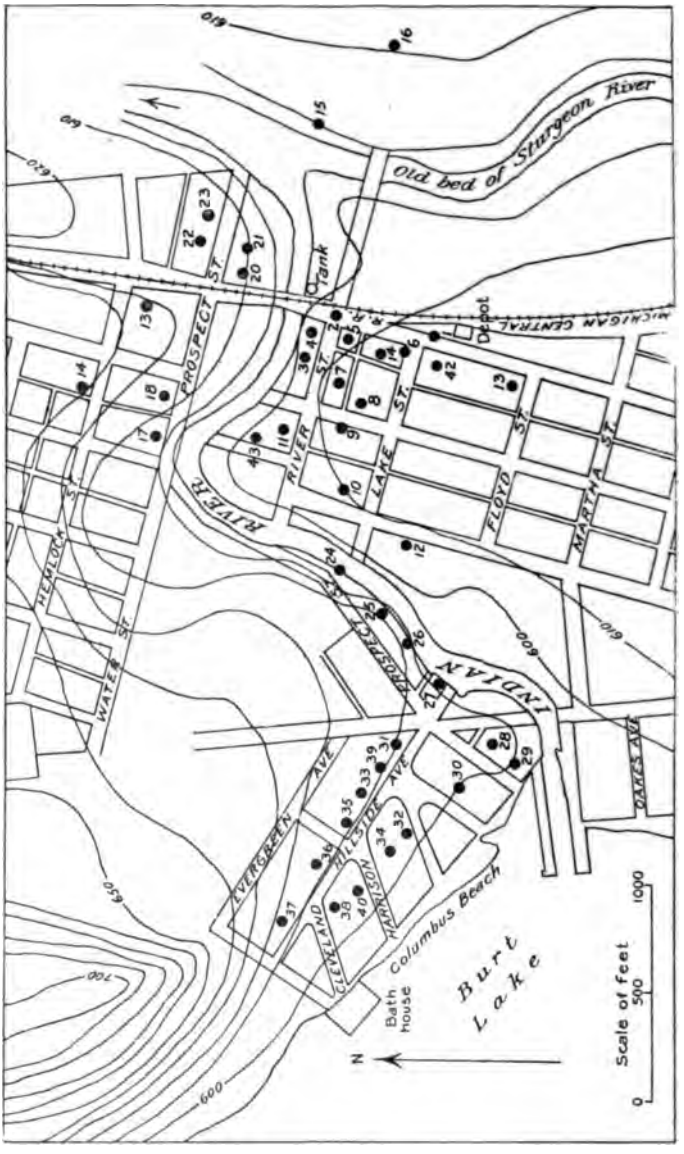


FIG. 65.—Contour map of Indian River flowing-well district.

The wells are drilled by contract, the price varying from $60 $125, according to the depth. The toughness of the clay beds a the presence of bowlders in a few of the wells renders drilling rat slow north of the river, and four days is the usual time for comp

g a well, though some of the wells with plenty of sand have been mpleted in two days. No rock has been reached and casing has ›t been found necessary except in wells where the sand was trouble-me.

In this area it is fortunate that the overlying beds are so impervi-ıs, otherwise much of the pressure would be lost and trouble would e experienced in leakage about the pipe, as is occasionally found in ells at Onekama and West Branch. In this region the wells are eatly appreciated, as is shown by the presence of a number of care-ılly piped wells with check valves, as the wells of Mr. Martin, '. H. Morgan, and others. At the summer resort of Columbus Beach ıe wells are carefully shut off for the winter.

Flow.—The total flow of wells in this district was determined y measuring wells flowing freely, and making estimates of those ith check valves and of those piped to several houses. Such esti-ıates have been starred in the tabulation of well data from this ea. Mr. Morgan, a practical well driller, is the authority for the ›w of a number of wells, which were measured at time of drilling. he total flow is 5,448 gallons a minute, which includes estimates ı wells which are reduced or have check valves. This is an aver-;e of 136.2 gallons a minute for each well and is the highest aver-;e of any well area examined in this region. The well having the rgest flow is that belonging to Mr. Mihan Green (No. 24 on table), hich out of several tests has given 224 gallons a minute as the aver-;e. No trouble has been experienced with a decrease in the head ıd no records are at hand to indicate any failure to obtain a supply.

In drilling for water in this area only one bed has been found which elds a usable flow. This bed is irregular in depth in various parts town and appears to dip slightly west to Burt Lake. It ranges in pth from 86 feet below the surface, as in the well of Mr. B. Field's o. 21) in the eastern part of town, to 175 feet at the Columbus each Club house (No. 38).

The bed is about 10 feet thick and is of rather coarse gravel, with a ght admixture of sand, which flows out in a few days after the well completed. The water bed may not be far above the rock, as at e Colonial Hotel, 4 miles northwest, rock is found at 140 feet, and 2 iles to the south rock ledges are present in hills which are 100 feet gher than the village.

The wells south of the river have sand beds at the surface from 30 50 feet thick, and the remainder is hard clay. The latter is varied a few of the wells by having many sand and gravel layers which eld some water, but not enough for a flow. North of the river hard-ın clay is on the surface and forms the larger part of the wells for out 40 feet, as at Mr. T. Dagwell's well (No. 17), which has a small

surface layer of sand and the remainder clay, the upper part of which contains bowlders.

The wells at Columbus Beach have the finest beds of sand midway of the depth and small beds of light-colored clay below. No failure to reach the water bed was reported, but there are wells which do not flow. The well at the public school (No. 41) did not flow, the water being about 10 feet below the surface. By cutting off the pipe and carrying the water down the hill some 10 feet a weak flow was made.

Well drillers will not try for a flow when the surface is over 30 feet above the water level of the river, and on the map (fig. 65) it will be seen that flowing wells are below the 640-foot contour. In all parts of the village south of the river flows may be found, but to the north the area is limited.

The wells have the strongest force near the river, and some of the homes are fitted up with flush closets and bathrooms, using the water in the same manner as a city supply. Mr. W. H. Morgan (No. 7) has sinks, closets, and bathroom; none of the water is wasted, as it is controlled by check valves. Mr. F. E. Martin (No. 2) has coupled both his wells to a small hand fire engine, which gives plenty of water, and a good pressure in case of fire. A small plant for village fire protection could be installed at small expense by use of a gas engine and small distributing pipes, or a portable hand engine fitted for quick connection with several wells scattered about the village. The Alcove Hotel has sinks for kitchen use, flush closets in second story, and 4 stationary stands in a wash room, all supplied from one well. The water from this well rose 23 feet in a hose attached to it, and with the nozzle at the mouth of the well the water went vertically 12 feet into the air.

Several ornamental fountains are operated by wells. Medbury's well (No. 34) supplies several families and a fountain; in the latter water rises 15 feet through a quarter-inch aperture.

The Indian River area is in a valley or lowland plain at the outlet of Burt Lake. To the south, about 685 feet above tide, is a sand plain, which is several miles wide and ends some 3 miles south of Indian River in morainal hills, which show rock outcrops up to 720 feet above tide, the drift surface being about 100 feet higher there and of much greater altitude farther south. There beds of loose-textured drift material, dipping to the north and covered by the later deposits of lake sand and clay, form the probable catchment area of the wells.

Clay, with a few bowlders, is present north of the village, but the highest hills in that direction scarcely reach an elevation of 850 feet. On the eastern side of Burt Lake the sand-capped clay is 40 feet above lake level, as shown by the abundance of springs. The porous overwash to the north may contribute somewhat to the flows of Indian

River, but the larger supply is believed to come from the beds to the south.

Quality of water.—Examination of water from several wells of Indian River shows that its hardness averages a little higher than that from Oden, Harbor Springs, or Conway. Complaints are frequent that the water is hard, requiring the use of softening compounds for laundry purposes, though it is excellent for drinking. Sulphates were absent from the waters examined, and chlorides were present in small amount. The hardness is easily remedied, and this is fortunate, for the chief use of the water in this district is for domestic purposes. The presence of iron was not indicated by tests or deposits of the carbonate about any of the wells. The results of testing wells by the field method are shown in the following analyses:

Field analyses of water from wells at Indian River.

[Parts per million.]

	1.	2.
Hardness	227	178
Carbonates	195	192
Chlorides	60	15
Sulphates	0	0
Iron	0	0

1. Alcove Hotel (No. 5). 2. T. C. Herrick (No 26.)

The temperature of the wells averages slightly above 48° F., which is 6° higher than the mean annual temperature of Indian River. The large flowage of water of this temperature into Indian River may acccount for its open condition in winter, while Sturgeon River without such a supply, is frozen

The temperature of the water makes it especially useful in domestic needs, doing away with the use of ice. In the general store of Mr. F. E. Martin an excellent butter room has been constructed in the basement by using the flowing water, which gives a satisfactory temperature for keeping dairy and farm products for the market.

The average temperature of these wells is exactly what sanitary officials of the larger cities demand for the storage of butter and milk during the summer months. This not only makes a well of especial value, but is an attraction to the summer residents.

The growth of algæ in the water is seldom sufficient to be an objection to its use. Indeed the wells generally are remarkably free from organic growths such as are due to water standing too long in tanks exposed to the sun's rays.

Wells at Indian River. [a]

No. on fig. 65.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*			
1	Town property	611	118	493	651	100	48			Supplies large fountain and 2 drinking founts.
2	do	605	112	493		100	48			
3	F. E. Martin [b]	603	108	495		c 190			$100	Made in 1895.
4	do	603	108	495		190				
5	Alcove Hotel [d]	605	107	498	628	c 200	48	Hard	125	
6	Commercial Hotel	611	115	496		115	48			
7	W. H. Morgan	612	124	488	647	205	48	Medium	70	Only a little softening compound needed.
8	E. Walkins	613	107	506		c 150				Supplies 2 families.
9	A. Clements	612	106	506		c 190	48½			Supplies 4 families.
10	J. Berry	610	122	488	627	150	48		50	
11	B. Clements	605	110	495		c 160	48½	Hard	65	Supplies 3 families; cased 100 feet; made in 1899.
12	D. Corwin	606	125	481	654	155	48½	do	60	Throws much sand; pressure, 22 pounds.
13	Dr. J. W. Bell	614	135	479	641	150	49½	do	55	
14	A. Bradley	611	108	503	631	150	49	do	50	Made in 1896.
15	Geo. Patterson	600	102	498		128		do		Made in 1899.
16	J. J. Donnely	610	120	490		130	49			
17	T. Dagwell	609	137	472					70	Not flowing in 1904; sand clogged.
18	H. B. Lauterman.	612	142	470	637	100	49	Hard	115	Made in 1897.
19	Jos. Frye	620	126	494	645	125	48½	do	60	Made in 1900; cased 120 feet.
20	J. Vermilya	610	108	502		120	49	Medium		Cased 40 feet through sand.
21	G. Fields	610	86	524		65			65	
22	J. W. Peck	615	93	522	625	175		Hard		Some water at 33 feet.
23	F. E. Martin	616	107	509		60				
24	Mahan Green	598	130	468		b 224	48		85	
25	H. P. Gordon	610	155	455		90	48½		80	
26	T. C. Herrick	610	165	445	650	130	47½			Pressure, 22 pounds.
27	W. R. Kinnear	600				130	47½			
28	Mrs. Hover	604	150	454		125	47½			
29	H. Burgess	600				100	48			
30	H. Barcus	600	175	425			48			Stopped by sand.
31	J. C. Brown	610	150	460		100				
32	T. L. McFee	604	170	434		108				
33	T. H. Dunn	612	130	482		c 180			85	Supplies 4 families.
34	Dr. Medbury	604	160	444	619	c 190	48		80	Supplies 5 families and fountains.
35	Mrs. J. B. Brown.	611	155	456		c 105				Supplies 2 families.
36	J. McFee	610	170	440		c 150				Supplies 3 families.
37	W. F. Brums	615	168	447		c 100			125	
38	Columbus Beach Club House.	605	175	430	640	c 150	48			Supplies 2 families and club house.
39	do	611	140	471		100				Pressure, 14 pounds.
40	J. Fieser	603	156	447		100	48	Soft		
41	Public school	630	175	455	624					No flow.
42	Joe Miller	613	113	500	647	110	48½	Hard	35	Cased 96 feet.
43	Crawley & Newman.	608	116	492		128	49	do	70	Pressure, 20 pounds.

So far as ascertained, the wells are 2 inches in diameter.

[b] In basement of F. E. Martin's store. The wells are connected and furnish water for 2 stores and a butter room and for 2 families over the store. One well is connected to a hand fire engine for fire protection.

[c] Wells controlled by faucets; flow estimated.

[d] By measurement at date of observation the water rises 23 feet, and when allowed to flow into the air rises 12 feet from the surface. It supplies the hotel and has sufficient pressure to operate the closets and wash basins on second floor.

MULLET AND BURT LAKES.

Wells at Burt Lake.

or location.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	°*F.*			
r Sweet	599	105	494		38				House use.
en farm	601	70	531		7		Soft	$50	Said to flow from rock.
. Thomas	603	108	495		20	48		80	Flow has decreased.
lumphrey	601	66	535		40			40	
rown	605	55	450	625	50	46			Domestic use.
'arks	608	107	501		6				
Sager	599	88	511		8	48	Soft		Weak flows at 46 and 70 feet.
D	599	97	502	609	12	48	do	100	Hotel, laundry, and domestic use.
Williamson	601	112	489		12				House use.
Parker	601	110	491	615	30			130	Do.
burg Land-	626	180	446		15	46			Club-house use.
ial Hotel	605	464	141		4	51	Hard		Hotel, kitchen, laundry.
Sager	599	99	500		36	48	Soft		Do.

Wells at Mullet Lake.

or location.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	°*F.*		
s Sons, Topina-	604	119	485		40	48	Soft	Shipped and carbonated; well, 3-inch.
ks	586	55	531	592	7	47½	do	Domestic use.
nhouse	585	28	557		5	47	do	Do.
dge	589	121	468	590	2	48	do	House supply; some H_2S.
	589	100	489		3		do	House supply.
Levington	590	60	530				do	Do.
, Topinabee	606	119	487	616	20		do	Domestic use; made in 1893.
Central station, e.		118						Made in 1903.
se. Topinabee		125						Do.

[a] Water shipped by H. H. Pike's Sons as "Sanitas Spring" water.

Analysis of Sanitas Spring water. [a]

	Parts per million.
	14.5
ionia	None.
in nitrates	23
dness	20.2
it hardness	17.1
and volatile matter (by loss)	18.2

ione; odor, none; taste, perfect; reaction, neutral. I. V. S. Stanislaus, analyst.

Field analysis of Sanitas Spring water.

	Parts per million.
	153.2
es	180
	.5
	214

Gregory, analyst.

's of Lower Michigan: Water-Sup. and Irr. Paper No. 102, U. S. Geol. Survey, 1904, p. 500.

WATER SUPPLIES OF EMMET COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Emmet County fronts on Lake Michigan at the west end of the Straits of Mackinac and extends south to include Little Traverse Bay. The part south of this bay was described in connection with the discussion of Charlevoix and Antrim counties, it being in the region of drumlins and finger lakes. From Little Traverse Bay eastward is a lowland strip, which runs through to Lake Huron past Burt and Mullet lakes in Cheboygan County. North of this and north of Little Traverse Bay are very prominent uplands rising in places to an altitude of 400 to 500 feet above Lake Michigan. These high tracts are composed of loose-textured drift, into which the water table sinks to a great depth. A well dug by a farmer, C. Cobleman, on one of the highest points in the northeast part of T. 36 N., R. 5 W., found the water table 400 feet below the surface. The well is 404 feet and water is drawn from the bottom. It was at first drawn by horsepower, the horse being driven around a drum, on which the rope was wound, but is now fitted with a 12-foot windmill wheel. Its bottom is probably 100 feet above Lake Michigan.

Near the west side of the highlands are blowing wells, also of great depth. One in sec. 29, T. 37 N., R. 6 W., on the farm of J. Bradley, was dug 300 feet and cemented all the way down. Then a boring 65 feet deep was made in the bottom to reach water. The well under certain barometric conditions has a strong down draft and under other conditions a strong upward rush of air. A whistle has been attached to the well, and this, it is said, is blown with sufficient force at certain times to be heard a mile away. Notwithstanding the great depth to the water table this upland carried a heavy forest growth, and orchards planted on it are not affected by drought. A large part of the rainfall seems to be kept within reach of the roots.

The lowland leading east of Little Traverse Bay and also the north border of the bay furnish strong flowing wells, which have been studied by Mr. Gregory, and are discussed below. It is probable that flowing wells can be obtained at moderate depth at the north border of the highland tracts just mentioned and in recesses along the shore of Lake Michigan, but none have as yet been reported. In the map accompanying Mr. Gregory's report the prospective, as well as present, flowing-well districts are represented.

The portion of the county south of Little Traverse Bay and of the lowland running east of the bay has limestone up to a height of 100 to 150 feet above the level of the bay and extends about to the middle part of the lowland, though at an altitude but little above the bay

rth of the lowland the rock surface, as indicated by the deep borings the uplands and by the deep flowing wells in the lowlands, is at a nparatively low altitude, and it may be largely below the level of ke Michigan. At the north end of the county, however, it outcrops heights of 75 to 100 feet above lake level and is penetrated at slight pth by nearly all the wells in Mackinaw City.

MISCELLANEOUS VILLAGE SUPPLIES.

The villages of Alanson, Oden, Conway, Wequetonsing, and Har- r Springs are supplied with flowing wells and but few others are in e (see pp. 365–378).

Data on the supplies of other villages and of the regions around untry post-offices are presented in the following table:

Village supplies in Emmet County.[a]

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
rr	850±	Wells and creek	6	12	12	12	.....	Small.
iss	800	Driven wells	.....	.....	35	.....	.....	Do.
utus	680	Open and driven wells	15	105	18	105	−2	Do.
rp Lake	724	Driven wells	16	30	16	16	.....	Do.
ell	.....	Driven wells, stream	35	60	40	40	−3	Do.
y	725	Wells and streams	20	40	30	40	.....	Large.
ssilon	.....	Open wells and streams	6	30	20	20	.....	Do.
odhart	.....	Open wells and lake	25	.....	.....	.....	.....	Do.
vering	760	Open and driven wells	25	200	25	120	−20	Small.
ttlefield post-office.	.....	Driven wells	10	230	50	50	.....	Do.
ackinaw	590	Open wells, lake	25	65	25	.....	.....	Do.
llston	690	Driven wells	16	24	24	24	−12	Large.
easant View	750±	do	22	25	25	25	−5	Do.

FLOWING WELLS.

PETOSKEY AND BAY VIEW.[b]

A well near the mouth of Bear Creek in the west part of Petoskey, out 10 feet above Lake Michigan, was sunk to a depth of 489½ feet d struck a strong flow of sulphur water at 295 feet beneath a thin d of blue shale.

Another well at Bay View, near the east end of Little Traverse Bay, an altitude about 5 feet above the bay, found under a very hard ratum of limestone, a flow estimated at 200 barrels an hour. In th wells limestone is near the surface, and the wells seem to belong a different class from those across the bay at Harbor Springs (see . 366–370), being unlike them in quality as well as in geologic lations.

[a] Not including those with flowing wells.

[b] Data by A. W. Grabau.

HARBOR SPRINGS AND WEQUETONSING AREAS.

General relations.—This area is a narrow strip of land not more than one-half mile in width and 5 miles in length, along the north shore of Little Traverse Bay (fig. 66). It is at the west end of an almost continuous belt of flowing wells extending from Harbor Springs on the Lake Michigan shore to Cheboygan on the Lake Huron shore. In fact, the Harbor Springs area is separated only by a strip of sand dunes from the remainder of the belt. To the north of this narrow artesian belt is higher land with loose-textured drift which in places reaches an altitude of 400 feet or more above the flowing-well district, while to the south an even higher altitude is attained within a few miles. This entire artesian district embraces the flowing wells of Cheboygan, Mullet Lake, Topinabee, Indian River, Burt Lake, Alanson, Oden, and Conway, as well as those of Harbor Springs and Wequetonsing. It lies along what is known as the "inland lake route" between the resorts on Little Traverse Bay and the city of Cheboygan on Lake Huron.

Records from different sections show the drift to be loosely consolidated at the surface, and succeeded by alternate layers of clay and somewhat consolidated gravel and sand, porous enough to take in water. The amount of underground water that the drift absorbs must be great, as may be inferred by the relative scarcity of small creeks or lines of surface drainage. The scarcity is greater in the highlands north of this flowing-well district than south, and it is probable that the main catchment area is on the north.

Within the limits of the Harbor Springs and Wequetonsing area there were 72 flowing wells in August, 1904, of which 41 were at Harbor Springs and 31 at Wequetonsing. The first well was drilled in 1887 by Charles Ross, being discovered accidentally while driving piles for a dock. When a pipe was driven through the clay into the underlying bed of gravel and sand the water rose 10 feet above the lake level and is still flowing. It is well No. 48 on accompanying table. Flowing wells of this class supply a large number of homes with abundant water, while the waterworks, owned by E. Shay & Co., derive their supply for public consumption from nine flowing wells, ranging in depth from 64 to 320 feet, and flowing 3,000,000 gallons a day.

The shallow wells are made by driving a 2-inch pipe with a strong point and screen to the water bed. Such wells cost from $50 to $70, including pipe and labor. The deeper wells are drilled and some are cased to shut off water from the upper bed, and cost from 75 cents to $1.30 a foot.

Flows from the upper water bed require frequent sand pumping to maintain a good flow. At present only a few are checked. No decrease in head has resulted from this practice, although some of the citizens

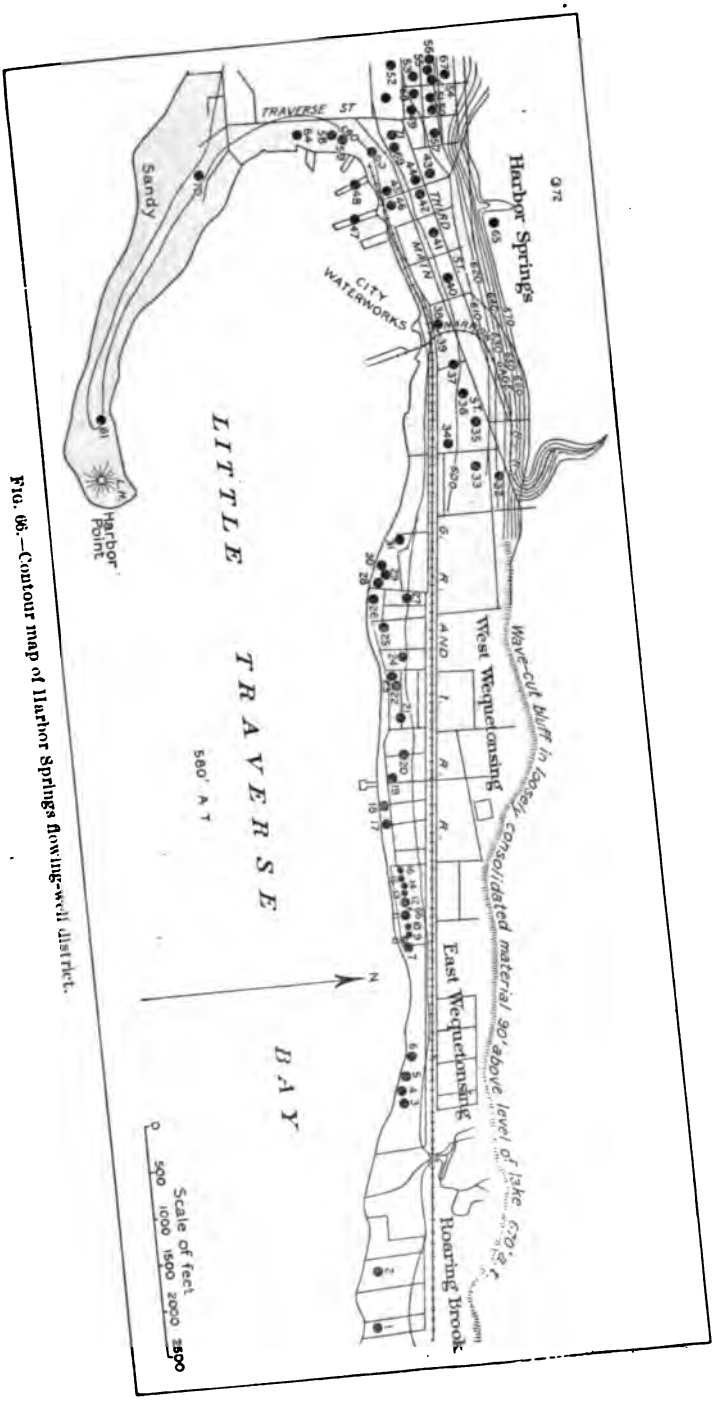


FIG. 66.—Contour map of Harbor Springs flowing-well district.

have agitated the question of having all the wells controlled. Some of the numerous fountains at Wequetonsing might be cut down with no inconvenience.

Flow.—The total flow of the Harbor Springs and Wequetonsing wells amounts to 430.9 gallons a minute, not including about 275 gallons a minute from the nine wells at the city waterworks. Aside from these the greatest flow is 33 gallons a minute from the well of Homer Clark (No. 55), which draws from the upper water bed. The well of Doctor Barr (No. 7) and Hughston (No. 6) have large flows, and are also from a shallow water bed. Mr. E. Shay, of Harbor Springs, has observed the wells since they were drilled, and states that the nine wells at the city waterworks have their flow increased as much as 10 per cent after a rainy season. Some of the well drillers claim that the flow from wells is greater during the spring than in the late autumn, but none of these statements are as yet supported by precise data.

At the Wequetonsing resort three water beds are developed. The upper is the stronger; it varies in depth from 30 to 40 feet in the eastern to 50 feet in the central part of the resort; on the western edge only a few wells draw their supply from it. The second bed is quite uniform in depth, being 60 to 70 feet down in the eastern and central and reappearing in a few wells in the western section. The third bed is the only one between wells Nos. 19 and 22 which gives a sufficient flow for water supply, although well drillers have found water at other depths. The wells are restricted to the bay shore below the terrace that passes through the north edge of Wequetonsing. The various beds at Harbor Springs have been penetrated at the city waterworks wells (No. 39), of which five are from 66 to 88 feet, three are 100 feet, and one (a 6-inch well) 320 feet deep. The following record of the material penetrated in the waterworks wells was obtained from Mr. E. Shay:

Record of waterworks wells, Harbor Springs.

	Thickness.	Total
	Feet.	*Feet.*
Sand	10	.....
Clay and sand	22	.....
Clay, some bowlders	30	.....
Hardpan	4	66
Gravel and sand (first water bed)	12	.....
Hard clay, no water	10	88
Sand and gravel (second water bed)	5	.....
Clay, no water, some bowlders	7	100
Sand and gravel (third water bed)	15	.....
Clay, blue and tough	50	165
Some gravel and sand in alternate layers (fourth water bed)	.....	260
Clay from 260 to 320 feet, which is near limestone rock	.....	320
Flow (fifth water bed).		

The records of wells nearer the shore than those of the city waterworks indicate that the beds dip toward the lake. At Harbor Point, at the light-house (No. 61), a depth of 291 feet, and at Harbor Springs

Park (No. 70), one of 300 feet, was reached without striking rock, the wells being entirely in sand. At the higher elevations in the town the water bed is penetrated at lesser depths than in the wells along the shore, as the wells of M. Losinger (No. 57), B. Barbour (No. 49), and George Wheeler (No. 67).

Quality of water.—The field analyses indicate that the sulphates are absent, while the carbonates are medium, the hardness about 160 parts per million, and the chlorides from 50 to 100 parts per million. The following analyses are representative of the water from this region:

Field analyses of water from wells at Harbor Springs.

[Parts per million.]

	1.	2.
Hardness	141	160.8
Chlorides	95.9	51
Carbonates	165	140
Sulphates	.....	0

1. Atkinson & Abbott (No. 46). 2. P. Pfister (No. 56).

Well data.—The following table gives the data of the wells of the region:

Wells at Harbor Springs and Wequetonsing.

No. on fig. 66.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Galls.*	° *F.*		
1	Doctor Barr	588	1	151	437	5.3	46¼	$125	
2	H. R. Pattengill	587	1	154	433	5.2	46	.....	Domestic use.
3	T. West	584	.5	74	510	.7	46¾	50	Do.
4	.....do	584	1.5	26	558	7.5	46½	.....	Fountain.
5	Mrs. Scott	586	1.25	44	542	15	45¾	.....	Domestic use.
6	Mr. Hughston	587	2	40	547	30	46½	.....	Fountain and domestic use.
7	Doctor Barr[a]	588	1	53	535	30	46½	50	Fountain and fish pond.
8	D. B. Little	587	1.5	73	514	4.5	46	.....	Fountain and domestic use.
9	Mr. Ferguson	586	1.25	80	506	12.5	46¼	.....	Domestic use.
10	S. C. Edgar	587	1.5	78	509	7.9	46½	.....	Head lowered by No. 8.
11	Mrs. Maxwell	585	1.5	73	512	4.6	46	50	Fountain and house use.
12	F. Eaton	588	1.5	79	508	6	46¼	50	Fountain.
13	Mr. Garrett	587	1.5	80	507	5.7	45	50	Fountain and house use.
14	Mr. Clark	588	1.5	64	524	4.8	46½	.....	Piped into house.
15	R. M. Bishop	588	1.5	80	508	2	46½	.....	Domestic use.
16	Mr. Smith	588	1.5	120	468	7.9	46	.....	Small fountain and house use.
17	Mr. McClure	584	3	74	510	6.8	47	.....	Fountain and house use.
18	.....do	584	1.5	73	511	3.3	46	50	
19	Mr. Brubaker (hotel)	587	1	144	433	3.3	46	100	Hotel lavatory, flush closets, and kitchen.
20	Mr. Pratt	589	1	191	398	1.7	46	.....	Small flow at 50 feet.
21	Mr. Brown	589	1.5	157	432	7.9	45	.....	House use.
22	A. C. Clifford	589	1	172	417	2.1	47	.....	Do.
23	C. Conklin	587	.....	178	509	.....	.....	.....	Small flows at 30 and 75 feet.
24	Mr. Roland	590	1	122	468	1.4	46	.....	Domestic use.
25	Mr. Reber	586	.75	131	455	1.5	46	.....	Do.

[a] The following is the record of Doctor Barr's well:

	Thickness (feet).
Sand	11
Hard clay	90
White sand and first water	10
Clay	30
Gravel and flow	10

Wells at Harbor Springs and Wequetonsing—Continued.

No. on fig. 66.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Galls.*	° *F.*		
26	F. Wyman	583	1	132	451	2.7	46	.....	Fountain and house
27	Mr. Eaton	590	1	144	446	3	46	.....	Domestic use.
28	Doctor Breed	586	1.5	52	534	8.3	46¾	.....	Piped to house.
29	Mr. Ferguson	586	1	63	523	4.5	46¾	.....	Domestic use.
30	Mr. Kennedy	584	1	54	530	3.5	46	.....	Do.
31	Mr. Strutt [a]	588	.75	185	403	1.4	46¾	.....	Do.
32	Mr. Johnson (saw-mill).	620	.....	41	579	.....	.....	$25	Used for steaming, by boiler compou
33	Village electric-light plant	603	.....	40 72	533	.....	.....	.....	Deeper well drained one.
34	Mr. McIntosh	595	1.5	144	451	1.9	47	.....	Garden and house u
35	Mr. Tanner	605	1	63	542	2.1	47	.....	House use.
36	E. Parameter	601	1.25	141	460	8.3	46	140	Head 607 feet; used f gardens.
37	Mr. Rockwell	599	1.25	100	499	7.8	46	70	House use.
38	Eight waterworks wells	595	1	66 150	548 445	.....	.....	.....	City supply; head 6
39	Deep waterworks well	595	.....	330	265	.....	.....	.....	City supply.
40	J. L. Thompson	601	.75	144	457	12	47	.....	Domestic use.
41	N. Moore	603	1	164	439	3.6	46½	.....	Water hard; suppli and several stores
42	F. R. Ferguson	604	2	112	492	10	46½	.....	Used at livery stabl
43	Mr O'Conner	605	1	112	493	3.7	.....	.....	Public fountain.
44	.....do.....	605	1	112	493	1.8	.....	.....	House use.
45	Thos. Lay	592	.75	102	490	6	46½	.....	Fountain and house
46	Atkinson & Abbott	592	2	48	546	10	46	48	
47	Northwestern Steamship Co.	589	2	63	526	10	47½	.....	Public drinking fou dock.
48	Rose Dock [b]	589	1.75	92	509	10	46½	.....	Head 599 feet; pion fountain on dock.
49	B. Barber	609	1.25	55	454	14	45.2	.....	Domestic use.
50	M. Juilleret	619	1.25	38	581	6.2	46	.....	Do.
51	F. R. Ferguson	619	1	35	574	1.3	46	.....	Water hard; flow creased somewhat
52	R. R. Ransom	608	.5	56	542	1.2	45¾	.....	Flow decreased by pipe.
53	H. Gillette	612	1	49	563	.5	48	.....	
54	W. Loundy	619	1	31	588	1.9	46	.....	House use.
55	Homer Clark	619	2	48	571	33.3	46	.....	
56	J. Pfister [c]	619	2	42	577	10	45.5	.....	Water soft; well re 1.5-inch.
57	M. Losinger	619	2	39	580	10.5	46½	.....	
58	J. L. Thompson [d]	589	2	100	489	20	.....	.....	Drinking, laundry cooking.
59	L. B. Densmore	590	.....	153	437	10	.....	.....	Domestic use.
60	Mrs. Crystler	590	2	120	470	18	46	.....	Do.
61	Light-house, Harbor Point.	591	2	281	300	.....	.....	.....	No flow; mostly sa clay.
62	Emmet Beach	.....	.....	112	.....	.....	.....	.....	West of Harbor not shown on cit
63	S. Olds	.....	.....	113	.....	.....	.....	.....	Do.
64	Grain elevator	588	2	160 80	428 508	.....	.....	.....	Two wells.
65	Schoolhouse	675	2	80	595	.....	.....	.....	Well on bluff; no f
66	Mr. Housler	588	2	164	424	.....	.....	.....	Domestic use.
67	Geo. Wheeler [e]	625	2	47	578	.4	45¾	20	Drilled in 1903; wa
68	M. J. Barnes [f]	612	2	85	527	.2	.....	.....	Domestic use; wat
69	Catholic school	601	2	145	456	.....	.....	.....	Pump well; water
70	Harbor Springs Park	595	.....	300	295	.....	.....	.....	Small flow; all san
71	Catholic school	601	2	56	.....	.....	.....	.....	No flow; pumped water soft.
72	J. S. Sharpstein?	683	.....	80	.....	.....	.....	.....	No flow; all clay;

[a] Small flows in gravel under clay at 40 and 60 feet.

[b] Pioneer well, made in 1887. Water at 45 and 92 feet. Water bed discovered while driving dock. Present well cased to lower water bed.

[c] Water excellent for laundry purposes. Water bed under hardpan. Weak flow at 36 feet

[d] Ram is used for forcing water into upper floor of house. The ram cost $13, and the compl and labor, including well, pipe, cooling room, bathroom, flush closet, and plumbing, $250. will pump about 420 gallons in ten hours.

[e] Weak flow at 15 and 35 feet from small gravel beds between clay. Made in two days.

[f] Does not overflow, but flows into underground cistern.

CROOKED LAKE AREA.

eneral relations.—The Crooked Lake area is part of the flowing-l district east of Harbor Springs and around Crooked Lake. (See 67.) The flowing wells of the region are located in the depression ;ussed under Harbor Springs (pp. 366–368), and range in altitude m 600 to 630 feet, which is their general elevation throughout the rbor Springs-Cheboygan region. The wells in the Crooked Lake a are located below a sandy terrace underlain with clay, which nds between the lake and the high morainic hills, and is well devel-

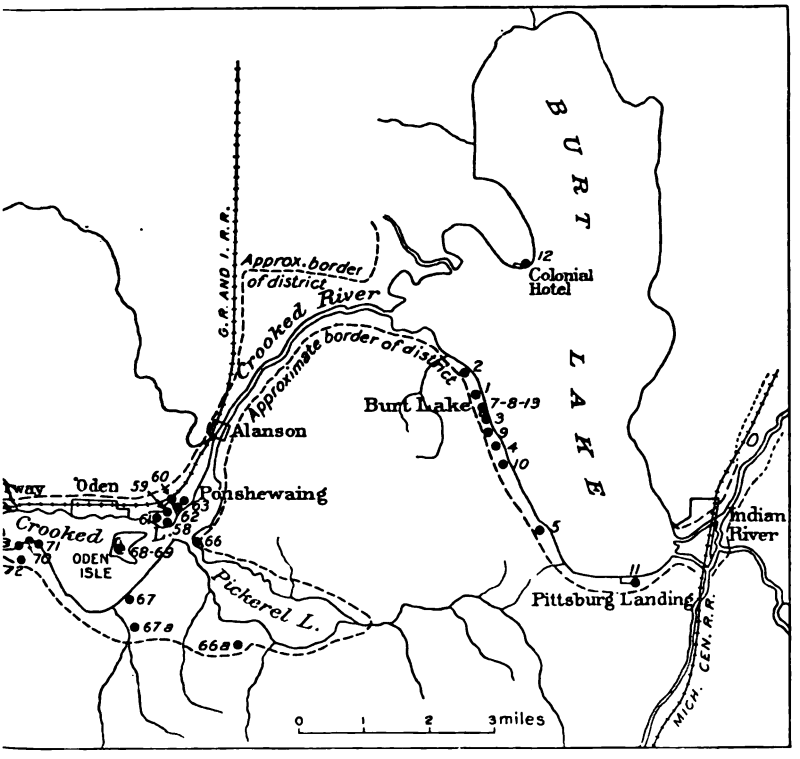


FIG. 67.—Sketch map of flowing-well region between Conway and Indian River.

:d from Harbor Springs to Alanson (altitude 640 to 650 feet). e edge of this terrace is 500 feet north of the Grand Rapids and liana depot at Oden (see fig. 68); it is just west of the depot at .nson, and one-half mile north of the depot at Conway. The her hills of loose-textured drift reach an altitude of 940 feet above within three-fourths mile north of Oden. This higher tract is an ;ward continuation of that north of Harbor Springs, and reaches laces an elevation of about 1,000 feet (Leverett). On the south of Crooked Lake limestone appears near the surface in the low ntry, but there is a rapid rise southward into a district with drum-

linoidal hills. Elevations of 300 feet above Crooked Lake are reached within 2 miles to the south.

The wells are best developed and strongest on the north side of the lake, chiefly at Oden, a few at Conway, Alanson, and Ponshewaing, while on the south side of the lake they are difficult to obtain and only a few exist. The part of the flowing-well area extending from Conway to Alanson is some 4 miles in length and varies from three-fourths to 1 mile in width. South of Crooked Lake its extent is not clearly defined, but it appears to be only a very narrow irregular strip not extending over a mile back from the edge of the lake. The wells about Crooked Lake number 100, 65 of which are at Oden, 14 at Conway, 8 at Alanson, and several on the south side of the lake.

The first effort to get a flowing well was made in 1884 at Oden in a search for suitable water for boiler use in the engines of the Grand Rapids and Indiana Railway. An excellent flow resulted, though the water was found to be too hard for use in boilers. The rapid increase of summer residents has made many demands for a water supply of

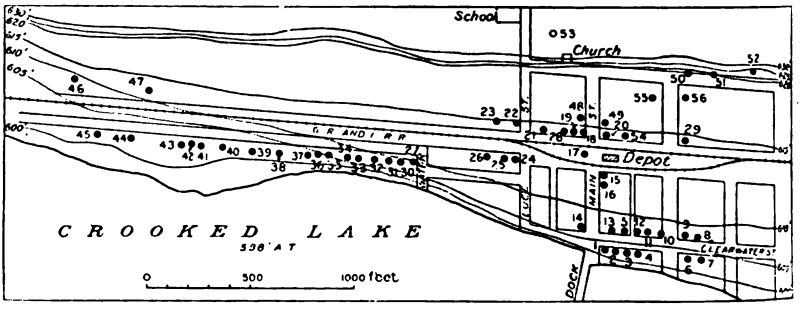


FIG. 68.—Contour map of Oden and vicinity.

this character and the number of wells has increased rapidly. The wells are drilled by contract, averaging from $40 to $60 complete. The depth of the water bed is so well known to the drillers that the time and labor as well as the cost of the material can be estimated very accurately.

Flow.—The total flow in this area is about 2,000 gallons a minute, of which the wells at Oden yield 1,362 gallons, at Conway 353, Alanson 147, Ponshewaing 145, Burt Lake 279, and Mullet Lake 77 gallons a minute. The strongest flow is that of the Grand Rapids and Indiana Railway well (No. 17) at Oden, which yields 80 gallons a minute. The wells on the south side of the lake have the smallest flow, and all attempts to secure better wells there have been failures. The water at Oden is allowed to flow freely and poor drainage of this surplus water is the cause of many swampy spots. In this growing summer resort such a supply of water is one of the valuable features, and where so many wells are being drilled it would be well to consider the

future conditions. There is some objection to using check valves, for when the water is checked the sand settles and fills the pipe, often completely choking the flow. The amount of sand that some of the wells bring to the surface renders the water unfit for domestic use and a settling tank on the roof or second floor of the dwelling has to be used. A large well screen with a small mesh would be a means of checking the sand. Small screens are used in a few wells, but have been discarded by owners because of a tendency to decrease the head.

In Oden three or more water beds are present, the lowest bed being the one in which the strongest flows are found. The majority of the wells are not drilled but are driven, and but little accurate data are available concerning the character of the beds. The writer's information has been furnished by the Pope brothers, who have had considerable experience in well drilling in this region. The Oden beds dip gently to the shore of Crooked Lake, with an additional dip from west to east, the stronger flows being found at 130 to 140 feet in the rail-

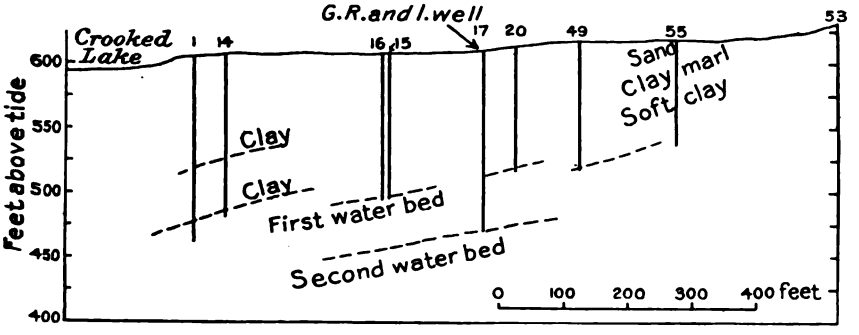


FIG. 69.—North-south section at Oden, showing water beds.

road well (No. 17), Mayer's well (No. 7), P. Smith's well (No. 2), and H. Rosenthal's (No. 28). In the western part of the village the stronger flows are from 100 to 110 feet, as in the wells of Mrs. Weil (No. 31), Doctor Shank (No. 42), and E. Mayer (No. 34). In the western part the beds are largely fine sand with smaller beds of marl and hardpan clay. The general relations in Oden are shown in fig. 69, which is a profile of water beds on a line drawn north and south from the Grand Rapids and Indiana Railway depot. The two beds which have been exploited for the majority of flows are under clay layers 5 to 6 feet in thickness. The water beds are usually fine sand with only a small amount of gravel. The depth of the upper bed averages from 75 to 95 feet, while that of the strongest flow averages 120 to 140 feet. Below this water is not abundant. For this reason the pipe in the railroad well (No. 17) after being put down to 180 feet was drawn back to the 140-foot flow. In the western part of Oden the upper bed is used for flows, as it is stronger there than to the east, and it is in this

part of the village that sand in the water causes considerable trouble, requiring settling tanks to get rid of it.

Bed rock is not reached in any of the Oden wells, but is penetrated 150 feet in the wells of the Dart & Dart Company on Oden Isle, in Crooked Lake, three-fourths of a mile southeast of the Grand Rapids and Indiana Railway station in Oden. This continuous belt of the Traverse limestone to the south, as shown in the outcrops of Bay View, may aid in preventing the escape of the water and thus keep the head up in the region around Crooked Lake.

The contour map of Oden (fig. 68) will serve as a local guide in selecting well sites. By locating the prospective well on the map and referring to the accompanying table of data for the records of the surrounding wells a fair estimate of the cost and character of the flow can be obtained. The 630-foot contour lines limit the field to the north. Below this contour from Oden west to Conway and east to Ponshewaing flows are to be obtained. On the large map of the region (fig. 67) the area in which flows are possible is indicated between the dotted line and the lakes.

The water beds at Conway have not been explored by drillers as fully as those at Oden. There are two distinct water beds present and possibly more. The well of F. Stallman (No. 10), 88 feet deep, is from the upper bed, which ranges from 88 to 115 feet from the surface. The sand bed supplies the strong flows of C. Lyon (No. 12), W. Van Avery (No. 6), and the depot (No. 4). The well of E. E. Blackmar (No. 14) penetrated the following materials: Sand, 35 feet; clay, 47 feet; gravel, 12 feet; clay, 13 feet.

The wells on the south side of Crooked Lake are nearly all in rock, and very few flows have been obtained. Mr. Jewell's well on the beach west of Hastings Point is a small flow from the rock. The Cincinnati Club at Hastings Point has a well 140 feet into rock, which yields a small flow. On Hastings Heights at the hotel, which is 628 feet above tide, several attempts for flows have been made. Limestone is reached at 18 feet below the surface and water at 252, but no flow, and the water is so scarce that the well has been abandoned. Several other attempts have been made along the beach to obtain flows, and, while some have been successful, at present they all require pumping to raise the water. There are two flows farther east on the south side of the lake which were not visited. One is at an old lumber camp. In the region to the southeast of Crooked Lake few deep wells have been made. Mr. George Benham drilled 150 feet, largely through bed rock, and found a small flow.

At Ponshewaing two water-bearing beds are present, the upper one being the stronger, as at Conway. The "Resort" well (No. 58) is from a bed of rather coarse gravel under 8 feet of sand, 15 feet of marl, and 48 feet of clay. The drillers find water from 100 to 15

t. Near the surface the beds are sandy and below are thin beds of ,y and gravel, no rock being found in the 200-foot well at the Ponewaing Hotel (No. 60) nor in Mr. L. Schwab's well (No. 63), which 225 feet deep.

The high morainic region, a short distance north of the Crooked ıke flowing-well belt, contains unconsolidated drift material well ited as a catchment area for the flowing wells along its south border. ›rings are very frequent along the edge of the higher land. The ›lls of Alanson, Pohshewaing, Oden, Conway, and Harbor Springs e all believed to be supplied from this catchment area.

Quality of water.—The water in the district north of the lake is ported soft, as it requires no special softening compound, and is in neral use for laundry and domestic purposes. At the Hotel Raw-ın, in Oden, a glycerine soap for use with this water has given best tisfaction. The Grand Rapids and Indiana Railroad have found e water unsuitable for boiler use, the deposit of scale being too eat. Dr. A. B. Prescott, Ann Arbor, Mich., said of the water taken ›m the railroad well (No. 17):

This water contains a moderate amount of lime, a good part of which is held in solution a carbonate. Sulphates are present in very small proportions and chlorides are not sent in any proportions that would affect uses. Iron salts are not present in more than ces. The hardness by Clark's scale is 11°, corresponding in effect to the presence of 11 ins of carbonate of lime in a United States gallon of water. In respect to the presence rganic matter the tests show a good degree of purity in this water.

The hardness in waters tested varies from 201 parts per million in Mayer's well (No. 34) to 186 parts in the Rawdon Hotel well (No. Carbonates average 156 parts per million. The rock well of the cinnati Club at Hastings Point has a hardness of 314, carbonates , and some sulphates.

Field analyses of water from wells at Oden and Conway.

[Parts per million.]

	1.	2.	3.	4.
dness	201	120.6	186.9	314
onates	160	160	166	320
rides	1	5	5	150
hates	None.	None.	None.	33
	None.	None.	.....	.....

E. Mayer (No. 34), Oden. 2. Rawdon Hotel (No. 1), Oden. 3. Depot (No. 17), Oden. 4. Cinati Club (No. 71), Conway.

Well data.—The following tables give the data of the wells of the region:

Wells of Crooked Lake area.

WELLS AT ODEN.

No. on fig. 68.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals*	°*F.*			*Feet.*	
1	Hotel Rawdon [a]	604	2	140	464	618	32	46		$140		
2	P. W. Smith	604	2	138	462		60	46				Domestic use.
3	E. Morrow	604	2	114	490							First clay at 90 feet.
4	Grand Rapids and Indiana Rwy. park.	603	1½				10	46				First flow, made in 1884, still flowing.
5	do	605	2	102								Park and bathhouse.
6	J. A. Andrews	603	2	105	498		30	46				2 wells connected: fountain, fish pond.
7	Mr. Mayers [b]	603	2	130	473	613	65	46				Domestic use.
8	Clubhouse	606	2	100	506		60	46	Hard	54		Domestic and laundry use.
9	A. Saunders	606	2	93	513	618	63	46				Sand 80 feet, clay 1[illegible] feet, gravel and sand 4 feet.
10	H. Gordon	605	2	96	509	617	40	46	Soft	60		Domestic use.
11	H. Tugar	606	2	96	510		50	46				House and barn.
12	J. Havlin	606	2	96	510		65	46				Domestic use.
13	R. B. Allison	606	2	106	500		50	46		59		
14	Oden House	607	1½-2	127	480		65	46		150		4 wells connected.
15	R. L. Marvin	609	2	114	485	614	32			30		Domestic and stock use.
16	H. Pope	608	2	113	485		25	46	Soft	15		Domestic use.
17	Grand Rapids and Indiana Rwy. depot. [c]	611	8	140	471	629	80	46				Drinking water.
18	V. Powell	614	2	130	484				Soft	30		
19	J. C. Carpenter	613	1½	140	473		50					Said to be nearly all quicksand. Hard pan at 95-100 feet and at 120 feet.
20	P. Tile	612	2	100	512		7	46	Soft	15		Butter cooler and domestic use.
21	C. Rush	613	2	114	499		29	46				Well driven in [illegible] hours.
22	G. Woodruff	615	2	113	502		32					Domestic use.
23	W. L. Murphy	615	1¼	112	503		30					House use.
24	Mrs. Ruggles	611	2	140	471		20	46				Domestic use.
25	J. Carpenter	611	2	123	488		25	46				Supplies 2 families.
26	Mrs. W. Smith	611	2	81	530		5	46	Soft			Domestic use.
27	E. Stricher	610	2	78	532				do			No flow, sand clogged.
28	H. Rosenthall [d]	616	2	140	476		25	46				Supplies 2 families.
29	G. Engle	614	2	90	524		50	46	Soft			Domestic use.
30	G. Williamson	609	2	65	544		8	45½		75		
31	Mrs. Weil [e]	609	2	110	501		35					3 wells connected, 110 to 115 feet deep.
32	M. Market	609	2	78	531	629	60	46	Soft			Settling tank used.
33	S. Johnson [f]	608	2	90	418	630	42	46	do			Domestic use.
34	E. Mayer	607	2	118	489		40	46		105		Settling tank; see analysis of water.
35	A. Fisher	605		73	532		10	46				House use.
36	P. Soldern	605	2	78	527	629	15	46				Domestic use.
37	I. Carus	604	2	77	527		10	45½	Soft			Do.
38	C. Daley	603	2	80	523		12		do			Supplies 2 families.
39	Mr. Forrester	603		70	533	629	15					

[a] Used in hotel for kitchen, laundry, drinking, and washing. A glycerine soap is found to be best for the wash room. A small water ram forces the water to the second floor. The first clay is at 80 feet, the second at 120 feet. The rest is sand.

[b] Three wells, 127, 133, and 130 feet, respectively. The two deeper ones are connected and feed a large fountain.

[c] Drilled for water supply for engines, but is not suitable. It is used for drinking on the Grand Rapids and Indiana Railway. At the time of drilling the water rose 18 feet above the surface. It was drilled 180 feet, but the supply being poor the pipe was drawn back to 140 feet. See analysis (p. 375).

[d] Flows were found at 60, 80, and 140 feet; the lowest is the strongest. Said to be decreasing.

[e] Supplies 3 families and a fountain.

[f] The water is carried to a large tank on the roof of the dwelling, where the finer sand settles; without this the water is not suitable for use. This form of settling tank has to be used with several of the wells.

Wells of Crooked Lake area—Continued.

WELLS AT ODEN—Continued.

No. on fig. 68.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			*Ft.*	
40	E. Thorpe	604	....	60 / 175	544	....	15	46	....	$75	....	2 wells, 175 and 60 feet.
41	P. Baumgarten	604	2	55	549	....	12	45½	....	....	....	Hard, compact sand; no clay.
42	Doctor Shank	604	....	101	....	....	10	45½	....	....	....	
43	J. Hendrick	604	2	75	529	....	8	45½	....	....	....	Domestic use.
44	J. Stenbeck	603	....	85	518	....	5	46	....	....	....	
45	Mr. Bell	602	2	70	532	....	....	....	....	25	....	Trouble with sand.
46	A. Hewey	610	....	65	545	....	10	45½	Medium.	35	....	Well hand driven.
47	J. Holmes	611	2	55	556	....	....	....	....	....	....	Not flowing in 1904.
48	G. Hughes	616	....	96	520	....	5	46	Soft	....	....	Made in 8 hours; hard clay at bottom.
49	Mrs. Beard	616	2	99	517	....	6	46	....	....	....	
50	W. Pope	624	....	75	549	....	10	46	Soft	....	....	Sand 10 feet, white clay 15 feet, hard clay 50 feet, small flow at 60 feet.
51	N. Fordman	625	2	73	542	....	10	46	....	....	....	House use.
52	Mr. Duncan	628	2	86	532	....	2	....	....	....	....	Small flow at 33 feet.
53	James Hart	631	....	83	548	....	....	....	....	....	....	No flow.
54	Mrs. Shaw	615	2	110	515	....	11	46½	Soft	60	....	Domestic use.
55	G. Wrens	618	2	85	533	620	1½	....	Hard	....	....	Throws sand at intervals.
56	M. Haey	618	2	76	542	....	7½	46	....	....	....	House use.
57	Chas. Engle	....	....	82	....	....	....	....	Soft	....	....	

WELLS AT PONSHEWAING.[a]

No. on fig. 67.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°F.			*Ft.*	
58	N. M. Kellam[b]	600	2	70	530	620	50	45	Soft	$20	70	Fountain.
59	N. M. Kellam[c]	610	2	180	430	....	25	....	....	100	140	Hotel and laundry.
60	N. M. Kellam	615	2	200	415	621	20	46½	Medium.	100	140	Log found at 50 feet.
61	R. L. Myers	619	2	175	444	....	15	....	....	100	140	
62	F. M Cappoc	610	2	225	385	615	10	46	Medium.	125	200	Domestic use.
63	Louis Schwab	612	2	225	387	....	8	46	....do	125	200	
64	Sawmill	600	2	82	518	....	17	45½	....	....	....	Steaming.

WELLS ON SOUTH SIDE OF CROOKED LAKE.

66	Warren Keelers	....	1½	100	....	....	2	....	....	....	....	Flows pipe quarter full.
67	Geo. Benham[d]	610	1½	150	....	....	2	....	....	....	....	All clay. Said to reach rock.
68	Dart & Dart Co.	600	2	84	....	....	3	....	....	....	....	On Oden Isle; small flow.
69	....do	603	2	152	....	....	....	....	....	....	....	Said to stop in rock.
70	John Hastings	615	2	63	....	....	1	47	....	....	....	30 feet to rock.
71	Cincinnati Club	628	1¾	140	....	....	1	48	....	....	....	See analysis (p. 375); 14 feet to rock.
72	Hotel Hastings	728	1½	260	....	....	....	....	....	....	....	Mostly in rock.
73	J. Jewell	605	2	40	....	....	3	....	....	....	....	Flow from top of rock.

[a] The pipes in all the Ponshewaing wells, except No. 58, are without screens.

[b] The following is the record of Kellam well, No. 58:

	Thickness (feet).
Sand	8
Marl	15
Blue and yellowish clay	48
Gravel and sand with water	1

[c] When well No. 59 is checked, well No. 60 flows one-third more.

[d] Mr. Benham is reported to have another flowing well at an old lumber camp in the NW. ¼ sec. 33, T. 35 N., R. 4 W., *which flows about 10* gallons a minute. This was not visited.

Wells of Crooked Lake area —Continued.

WELLS AT CONWAY.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
	Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			*Ft.*	
W. Day	....	2	172	....	....	10	....	....	....	....	Domestic use.
N. Blackmar	606	2	165	441	....	15	46	Soft	....	....	Clay 125 feet; rest sand.
N. McFarlane cottage (2 wells)	606	1½	160 161	446	....	30	....	....	....	....	
Grand Rapids and Indiana Rwy. (depot).	605	2	115	490	625	30	46	Soft	....	....	
Mr. Mathews	....	2	116	....	....	15	46	....	....	....	House use.
W. Van Avery	603	2	100	503	....	50	46	Soft	....	....	House and store use.
V. Powell	604	2	103	501	....	18	....	...do	....	....	Carefully piped.
J. McFarlane mill	604	2	120	484	....	19	....	....	....	....	Drinking.
W. Rice	604	2	100	....	....	....	....	....	....	....	Not flowing.
F. Stallman	601	2	88	513	616	35	46	Soft	....	....	House use.
A. Blackmar	....	2	100	....	....	15	....	....	....	....	Small hotel.
C. Lyon	605	2	110	585	....	64	46	Soft	....	....	House use.
J. Cook	604	1½	100	504	....	20	....	....	....	....	Do.
E. E. Blackmar	603	1½	107	505	638	32	....	Soft	....	....	Made in 1885.

WELLS AT ALANSON.

E. R. White	609	2	82	527	....	10	45	....	....	....	Domestic use.
G. W. Rotten	607	....	72	535	....	8	....	....	$60	....	Do.
Colby Hinckly Co.	608	2	80	528	618	18	....	....	....	....	Do.
F. Keiger	614	2	96	518	634	50	45	....	100	....	House and barn.
H. McPhee	610	2	122	488	....	16	45½	....	100	....	Drilled in 1898.
J. McPhee	608	1½	90	518	....	15	....	....	65	....	Store.
W. McDonald	605	....	65	540	....	20	....	....	....	....	House use.
H. Fairbanks	603	2	70	533	....	10	46	....	75	....	Drinking.

WELLS NEAR BRUTUS (SEC. 34, T. 36 N., R. 4 W.).

Joseph Morris[a]	625	2	65	570	647	20±	....	Soft	....	....	Fish pond and stock.
Do.	625	2	55	570	647	20±	....	....do	....	....	Do.

[a] Two wells in a valley near the Grand Rapids and Indiana Railway, about 30 feet below the bordering plain, flow a full 2-inch pipe. Reported by owner; not visited.

INDEX.

A. Page.

vance, wells at 346
ron, wells at 141, 146-147
ron Township (Tuscola County), wells in 139, 140
nson, wells at 365, 366, 371-372, 375, 378
a, wells at 345
ee Township (Saginaw County), wells in 197, 199-200
na, water supply at 309
na County, flowing wells in 307
rainfall in 10
springs in 308
topography of 306-307
village supplies in 308-309
wells in 307-309
record of 308
water of, temperature of 16
n, wells at 335
r, wells at 281
nquin, Lake, location of 6
nquin Beach, location of 6
gan County, rainfall in 10
wells in, water of, temperature of 16
a Creek, water supply of 62
a, waterworks at 204
wells at and near 203, 204-212
wells in, location of, map showing 205
records of 206
a Sanitarium, well at, record of 206
na, rainfall at and near 11
waterworks at 351
wells at 351
na County, rainfall in 10
topography of 350
village supplies and waterworks in 351
wells in 351
water of, temperature of 16
na, wells at 79
adore, wells at 249
ber, wells at and near 80, 82
lith, well at 118
Arbor, springs at 16
springs at, temperature of 17-20
temperatures at, variations in, chart showing 19
waterworks at 22
wells at and near 130
water in, temperature of 15, 17-20
variation in, chart showing 20
im, wells at 345
im County, flowing wells in 335-339
akes in 333-335
rainfall in 10
opography of 333-335

Page.

Antrim County, village supplies in 345
waterworks in 336, 344
wells in 348
water of, temperature of 16, 337
Appin, wells at 260
Applegate, wells at 249
Arbela Township (Tuscola County), wells in 137, 139, 143-144
wells in, record of 144
Arcada Township (Gratiot County), wells in 272, 204-212
Arcadia, wells near 296
record of 296
water from, force of, plate showing 272
Arenac, wells at 281
Arenac County, flowing wells in 269-274
maps of parts of 270, 272
rainfall in 10
topography of 269
village supplies in 281
waterworks in 269
wells in 269-274, 279-280
water of, temperature of 16
Argentine, wells at 171
Argyle, wells at 249
Argyle Township (Sanilac County), wells in 257
Arkona Beach, location of 6
Artesian areas, map showing 6
Ashland, wells at 75
Ashley, wells in and near 204, 225-229
wells in and near, location of, map showing 227
water of, analysis of 226
Ashmore, wells at 260
Ashton, wells at 90
Ashton Township (Newaygo County), wells in 68, 69, 70
Atlanta, spring near 349
wells at 350
Atlas area, wells in 172
Atlas-Hadley area, wells in 173-175
wells in, location of, map showing 174
Atlas Township (Genesee County), wells in 172-175
wells in, location of, map showing 174
Atwood, wells at 345
Auburn, well at 116
well at, record of 116
Augres, wells at 269, 271, 281
Au Sable, waterworks at 269, 281
Au Sable River, source and drainage of 305, 307, 310, 311, 347, 349
wells on 306
Avondale, wells at 90
Ayr, water supply at 365

B. Page.
Bachelor, wells at 80, 82
Bad Axe, waterworks at 259–260
wells at 258, 260, 264
Bagley, wells at 348
Bailey, water supply of 26
Baldwin, lakes near 82
wells at 83
Bamfield, water supply at 309
Bangor Township (Bay County), wells in. 119, 120
Bannister, wells at and near 214, 224–225
wells in and near, location of, map showing 224, 227
Barker Creek, wells at 312, 313
Barry County, rainfall in 10
wells in, water in, temperature of 16
Barryton, wells at and near 76–77, 79, 91
wells at and near, location of, map showing 76
Bass Lake district, wells in 80–81
wells in, location of, map showing 80
Bay City, waterworks at 120–121
Bay County, artesian map of 116
flowing wells in 115–118, 269–271
map of part of 270
rainfall in 10
topography of 117–118
waterworks in 120–121
wells in 115–120
water of, character of 120
temperature of 16, 120
Bayport, wells at 259, 260
Bayport Township (Huron County), wells in 266
Bay Shore, waterworks at 345
wells at 346
Bay View, wells at 365
Beaches, Glacial lake, location of 6
underground water on 7
Bear Creek, drainage of 293
wells on and near 293, 295, 343
Bear Lake (Manistee County), wells at 297
Bear Lake (Muskegon County), location of. 32
water from 26
Beaver Island, wells on 346
Beaver Township (Bay County), wells in ... 116, 118, 119
Beebe, wells at 229–230
Bellaire, waterworks at 344
wells at 8, 336–337, 338, 345
water of, analysis of 340
Belmont Beach, location of 6
Benson, water supply at 303
Bentley, wells at 119
Benzie County, flowing wells in 325–330
map of part of 327
rainfall in 10
section in 329
topography of 324–325
village supplies in 331
waterworks in 330–331
wells in 325–331
records of 328, 329
water of, analyses of 328
temperature of 16
Benzonia, section near 329
wells at 324, 327–330, 331

Page.
Berea sandstone, water in ..... [illegible]
Berne, wells at ..... [illegible]
Berrien County, rainfall in ..... [illegible]
wells in, water of, temperature of ..... [illegible]
Bethany Township (Gratiot County), wells in 93, 219–221
wells in, location of, map showing 221
Betsy River, drainage of ..... [illegible]
wells on ..... [illegible]
Beulah, wells at ..... 325, 327–[illegible]
wells at, records of ..... [illegible]
water of, analyses of ..... [illegible]
Big Prairie, wells at 73
Big Rapids, waterworks at ..... [illegible]
Big Rock, wells at ..... [illegible]
Bingham Township (Huron County), wells in ..... [illegible]
Birch Run Township (Saginaw County), wells in ..... 197, [illegible]
Biteley, wells at 73
Black Creek, wells on ..... [illegible]
wells on, record of ..... [illegible]
Black River, drainage of ..... [illegible]
topography on ..... [illegible]
water from ..... [illegible]
wells on ..... [illegible]
Black River (post-office), water supply at .. [illegible]
Blanchard, well near ..... [illegible]
Bliss, wells at ..... [illegible]
Bloomfield Township (Huron County), wells in ..... [illegible]
Boardman River, drainage of ..... [illegible]
water from ..... [illegible]
analysis of ..... [illegible]
Bog lime, water from ..... [illegible]
Bolton, wells at ..... [illegible]
Boone, wells at ..... [illegible]
Bored wells, description of ..... [illegible]
use of ..... [illegible]
Borland, wells at ..... [illegible]
Bowman, Isaiah, on Ensley district ..... [illegible]
work of ..... [illegible]
Boyden, well near ..... [illegible]
well near, record of ..... [illegible]
water of, analysis of ..... [illegible]
Boyne waterworks at ..... [illegible]
wells at and near ..... 8, 341–342, [illegible]
water of, analysis of ..... [illegible]
Boyne Creek, wells on ..... [illegible]
Boyne Falls, wells at and near ..... [illegible]
Branch, wells at ..... [illegible]
Branch County, rainfall in ..... [illegible]
wells in, water of, temperature of ..... [illegible]
Brant Township (Saginaw County), wells in ..... 197, [illegible]
Breckenridge, wells at and near ..... [illegible]
Brent Creek, wells near ..... [illegible]
Brethren, wells at ..... [illegible]
Brice, wells at ..... [illegible]
Bridgeton, wells at 73
Bridgeton Township (Newaygo County), wells in 68, 69, 70
Brookfield Township (Huron County), wells in ..... [illegible]
wells in, record of ..... [illegible]
Brown City, waterworks at ..... [illegible]

Page.
, wells at 249
wells at 75
ls at 365, 378
lls at 309
hip (Sanilac County), wells in. 252-253
wnship (Shiawassee County), wells in 191-192
, location of, map showing 191
spring near 355
ar 354, 357, 363, 366
vnship (Genessee County), wells in 161, 166-168
, location of, map showing 162
wells at 305
Township (Missaukee County), well in 304
, wells at 82
s near 191

C.

water supply of 62
vations near 5, 301
orks at 301, 302
..... 303
er of, analyses of 303
unty, rainfall in 10
water of, temperature of 16
ners, water supply of 26, 45
ells at 260
lls at 83
at 146, 151-152
, record of 152
wells at 332, 365
at 82
waterworks at 248
..... 249
ells at 260
ownship (Huron County), wells in 266
supply at 249
s in, causes and results of 127
aterworks at 25, 26
strict, topography of 27, 41-42
..... 42
'ownship (Muskegon County), wells of 41-42, 45
vells at 151
, rainfall in 10
water of, temperature of 16
drainage of 246, 256
..... 134, 141, 143, 145-146
areas, distribution of 5
s at 351
of head due to 128
supply at 365
, drainage of 175
wells at 315
oor, wells at 260
ship (Emmet County), wells in. 364
e, waterworks at 344
..... 336, 337 338, 345
er of, analyses of 337
. T. C., water-supply data collected by 1
ownship (Huron County), wells in 266-267

Page.
Chapman Lake, well on 282
Charlevoix, waterworks at 346
wells at 346
Charlevoix County, flowing wells in ... 335, 339-344
lakes in 333-335
rainfall in 10
topography of 333-335
village supplies in 346
waterworks in 345-346
wells in 348
water in, temperature of 16
Charlton, wells at 348
Chase, wells at 83
Cheboygan, waterworks at 335
wells at 355, 357, 366
Cheboygan County flowing wells in .. 354, 355-363
lakes in 353
map of part of 358
rainfall in 10
springs in 354-355
topography of 353
village supplies and waterworks in 355
wells in 354-363
water in analyses of 356, 361, 363
temperature of 16, 355, 361
Cheboygan River drainage of 347, 352
Chesaning Township (Saginaw County), wells in 197, 200
Chestonia, wells at 345
Chicago Lake, location of 6
Chief, wells at 295
Chippewa Lake, wells at 79
Chippewa River, drainage of 75, 92, 243
Chippewa Township (Isabella County), wells in 93, 100
Chippewa station, wells at 90
Churn drill, use of 13
Chute Creek, wells on 117
Clam lakes, water from 301, 302
Clare, waterworks at 112
well near, record of 105
Clare County, flowing wells in 113
map of part of 107
rainfall in 10
topography of 111
village supplies and waterworks in 112
wells in 93, 106, 108, 111-113
water of, temperature of 16
Clarence, wells at 112
Clarion, wells at 344, 346
Clinton County rainfall in 10
wells in, water of, temperature of 16
Clio district, wells in 156
Clogging, instances of 31, 35-36
loss of head due to 128-130
Coal, occurrence of 140
Coal measures, wate from 7
Coe basin wells in 93, 94-95, 97-100, 244
wells in, location of, map showing 95
record of 96
Coe Township (Isabella County), wells in .. 93, 95-96, 98-99
wells in, details of 94
wells of, records of 96
Cohoctah area, wells in 180
wells in, location of, map showing 180

Page

Coleman, wells at and near..... 102
Colfax Township (Huron County), wells in. 264
Columbia Township (Tuscola County), wells in..... 137, 139, 140
Columbus Beach, wells at..... 357-360
Comins, water supply at 310
Contours, map showing 8
Conway, wells at and near..... 365, 366, 371-372, 374-375, 378
wells at and near, location of, map showing..... 371
water of, analysis of..... 375
Cooper, W. F., on Bay County..... 115-121
work of..... 3, 193
Copemish, wells at..... 296
Corunna, waterworks at..... 193
wells at..... 193
Corwith, wells at..... 348
Crawford County, description of..... 310-311
rainfall in..... 10
wells in..... 311
water of, temperature of..... 16
Crooked Lake, wells at..... 112
Crooked Lake area, wells in..... 371-378
Croswell, waterworks at..... 247
water supply at..... 249
Croton, wells at..... 75
Crown, wells at..... 260
Crump, well at..... 119
Crystal Lake, wells on..... 325, 327
wells on, location of, map showing..... 327
Crystal Valley water supply of..... 62
Crystal Valley district, well of..... 53-54
wells in, location of, map showing..... 54
water of, analysis of..... 91
Culver Creek, wells on. 115
Custer, wells at..... 82
Custer Township (Sanilac County), well in.. 256

D.

Davis, C. A., on Saginaw Bay drainage basin..... 121-246
work of..... 2
Davison, wells at and near 161-166
wells in, location of, map showing..... 163
Davison Township (Genessee County), wells in..... 128, 155, 161-166, 167-168
wells in, location of, map showing..... 162
Dayton Township (Tuscola County), wells in..... 143
Deckerville, wells at..... 249
Deerfield Township (Isabella County), wells in..... 108
wells in, record of..... 109
water of, analysis of..... 109
Deerfield Township (Livingston County), wells in..... 180-181
Deford, wells at..... 154
Denmark Township (Tuscola County), wells in..... 139
Denver Township (Isabella County), wells in..... 93
wells in, record of..... 101-102
Depth, influence of, on temperature..... 14-15
Detroit, population of..... 24
water supply of..... 24
Detroit River, wells on..... 7

Page

Deward, wells at..... 311
Dewings, wells at 90
Diamondlock, wells at..... 73
Dighton, wells at. 90
Ditching, drainage by..... 202-203, 228-229
loss of head due to..... 131
Dolph, wells at and near..... 304
Douglas Lake, spring near 354-355
wells near..... 354
Dover, well at..... 348
well near, record of..... 166
Dover Township (Otsego County), wells in. 347
Drainage, character of..... 9-10
See also Topography.
Drainage, subsoil, loss of head due to..... 131
Drift, character of 8
distribution of..... 5
structure of..... 8-9
water from, character of..... 7, 132, 136-137, 141-142, 157
See also Topography.
Drilling, use of..... 13
Driving, imperfect, loss of head due to..... 127
Drought, loss of head due to..... 130-131
Drumlins, distribution of..... 6
Dublin, wells at. 296
Dug wells, dangers of 12
description of..... 12
utilization of..... 124
Durand, wells in..... 192
Dwight Township (Huron County), wells in..... 268

E.

Eagle Bay, wells at..... 269
East Jordan, waterworks at..... 346
wells at..... 8, 339, 346
water of, analysis of..... 360
East Jordan—South Arm district, wells in..... 339-360
Eastport, wells at. 345
East Tawas, waterworks at 269, 274, 275
wells at 269, 281
Eaton County rainfall in..... 10
wells in, water of, temperature of..... 16
Echo, wells at..... 345
Edenville Township (Midland County), wells in..... 102
Edgewood, wells at..... 230
Edwards, wells at and near..... 115, 2[illegible]
Edwards district, wells in..... 11[illegible]
Edwards Lake, well on..... 2[illegible]
Elba Township (Gratiot County), wells in.. 204, 224-22[illegible]
Elbridge, water supply of..... 6[illegible]
Elbridge district, wells of..... 54-5[illegible]
wells in location of map showing..... 5[illegible]
water of, analysis of ..... 9[illegible]
Elevations, height of. ..... 4-[illegible]
Elk Rapids, waterworks at..... 344, 34[illegible]
Elkton, wells at. ..... 260, 26[illegible]
Elkton beach, location of ..... [illegible]
Elk Township (Sanilac County), wells in.. 253-25[illegible]
Ellsworth, wells at..... 34[illegible]
Elmer wells at ..... 34[illegible]
Elm Hall, wells at..... 2[illegible]

Page.
at and near..... 345, 347
gs near..... 214
ınd near..... 214-215
ıpply at..... 365
lls at..... 79
ıty, blowing wells in..... 364
vells in..... 335, 364-378
parts of..... 367, 371, 372
n..... 10, 364
f, figure showing..... 373
phy of..... 333-335, 364
ıpplies in..... 365
ırks in..... 368
..... 364-378
rd of..... 368, 369
ır of, analyses of..... 369, 375
emperature of..... 16
s at..... 333
nship (Newaygo County), wells
n..... 63, 73-74
location of, map showing..... 73
rd of..... 73
er supply at..... 365
rworks at..... 84
and near..... 84, 85-87
ır of, analysis of..... 91
ct, wells of..... 85-87
location of, map showing... 85
ır of, analysis of..... 91

F.

vells at..... 147-148
record of..... 147
Township (Tuscola County),
wells in..... 139, 140
'ownship (Huron County), wells
n..... 259, 266
wnship (Grand Traverse County), wells in..... 319
ater supply of..... 310
terworks at..... 112
erworks at..... 171
..... 171-172
nship (Genessee County), wells
in..... 171-172
at..... 82
r at, analysis of..... 91
ıpply of..... 62
ct, wells of..... 57-58
, location of, map showing..... 57
vells near..... 312, 314
lls at..... 345
ıvenport, on Muskegon well
water..... 37
use of well water for..... 125-126
ells at..... 351
lls at..... 312
in and near..... 131, 158-160
and near, record of..... 159
er of, analyses of..... 158-159
, drainage of..... 183
ı..... 158, 160
ıship (Genesee County), wells
in..... 158, 160
k, water of..... 49
ık district, wells in..... 46-49

Page.
Flower Creek district, wells in, location of, map showing..... 46
wells in, water of, analysis of..... 91
Flushing, wells near..... 158
Forest beaches (Upper and Lower), location of..... 6
Forest Hill, wells at..... 218
Forest Home Township (Antrim County), wells in..... 337, 338
Forests, distribution of..... 5
Forest Township (Genesee County), wells in 156
Forestville, water supply at..... 249
Fork Township (Mecosta County), wells in. 76-77
Forman, wells at..... 83
Fostoria, wells near..... 151
Fountain, water supply of..... 82
Fountain Point, wells at..... 323
Frankenlust Township (Bay County), wells in..... 119, 120
Frankfort, waterworks at..... 330
wells at..... 325, 330, 331
Fraser Township (Bay County), wells in... 117, 118, 119
Frederick, wells at..... 311
Freedom, wells at..... 355
Freesoil, wells at and near..... 80, 82
Freiburger, wells at..... 249
Fremont, waterworks at..... 66
wells at..... 65-67, 69, 70, 75
location of, map showing..... 65
water of, analysis of..... 91
Fremont district, wells in..... 63, 65-70
wells in, location of, map showing..... 69
water of, analysis of..... 91
Fremont Lake, well at, arrangements at, figure showing..... 67
wells at..... 67-68, 70
water of, analysis of..... 91
Fremont Township (Saginaw County), wells in..... 197, 199
Fremont Township (Sanilac County), wells in..... 252
Fremont Township (Tuscola County), wells in..... 143, 144
Frost, well at..... 197, 200-201
well at, water of, analysis of..... 201
Fruitland district, topography of..... 27, 41
wells of..... 41, 42
Fruitport, well at, record of..... 39
well at, water of, analysis of..... 39
Fruit Township (Muskegon County), wells in..... 39-40, 45
wells in, water of, analysis of..... 40
Fuller, M. L., analyses collected by..... 90-91
on Mason County..... 80-82
on Mecosta County..... 75-79
on Newaygo County..... 62-75
on Oceana County..... 46-62
on Osceola County..... 84-90
work of..... 3

G.

Gagetown, wells at..... 149
Gaines, wells at..... 170
wells in and near, location of, map showing..... 169
Gaines Township (Genesee County), wells in..... 169-170

Page.
Gaines Township (Genesee County), wells in, location of, map showing.... 169
Gale, water supply of..... 62
Garfield Township (Bay County), wells in. 119
Garfield Township (Grand Traverse County), wells in..... 314
Garmer, wells at..... 90
Gaylord, wells at and near..... 347–348
Genesee County, flowing wells in..... 125, 155–175
maps of parts of..... 157, 160, 162, 163, 169, 174
rainfall in..... 10
springs in..... 171
topography of..... 155
waterworks in..... 156–158, 164, 171
wells in..... 131, 155–175
record of..... 159
water of, analysis of..... 158, 159
temperature of..... 16
Genesee Township (Genesee County), wells in..... 160–161
wells in, location of, map showing..... 160
Geneva Township (Midland County), wells in..... 93, 102, 245
Geography, description of..... 4–6
Geology, description of..... 4–9
map showing..... 8
Geologic history, outline of..... 4–6
George Lake, well on..... 282
Geyser Spring, description of..... 89–90
Gibson Township (Bay County), wells in.. 119
Gifford Township (Tuscola County), wells in..... 139
Gilbert, wells at..... 303
Gilmore Township (Isabella County), wells in..... 92–93, 106, 108
Glacial epoch, history of..... 4–6
Glacial lakes, description of..... 6
Glaciers, distribution and character of..... 4–6
Gladwin, waterworks at..... 114
Gladwin County, flowing wells in..... 113–115, 269
rainfall in..... 10
topography of..... 113
waterworks in..... 114
wells in..... 113–115
water of, temperature of..... 16
Gladwin district, wells in..... 114
Goocha, J. B. F., on Otsego County wells.. 348
Goodell, wells at..... 75
Goodhart, water supply at..... 365
Goodrich, wells at..... 172–173
Goose Lake, well on..... 336
Gordon, C. H., work of..... 248
Gotts, wells at..... 260
Gove Township (Huron County), wells in.. 268
Grabau, A. W., on Petoskey and Bay View. 365
Grace, wells at..... 353
Grand Blanc, water supply of..... 171
Grand Haven, rainfall at and near..... 11
Grand Rapids, wells at and near..... 7
Grand River, drainage of..... 183
Grand Traverse Bay, wells near..... 16
Grand Traverse County, flowing wells in. 315–326
map of part of..... 316
sections of..... 317, 318
rainfall in..... 10
springs in, analysis of..... 321–322
Page.
Grand Traverse County, topography of.... 314
village supplies in..... 315
wells in..... 314–324
records of..... 322, 323
water of, analyses of..... 318, 321
temperature of..... 16
Grant, wells at..... 73
Grant Township (Clare County), wells in..... 93, 106, 108
Grant Township (Huron County), wells in. 268
wells in, record of..... 269
Grant Township (Newaygo County), wells in 63, 73
Grasmere beach, location of..... 6
Grassmere, wells at..... 280
Gratiot County, flowing wells in..... 125, 204–229
map of part of..... 205, 215, 216, 221, 224, 227
rainfall in..... 10
springs in..... 214, 219
topography of..... 202–206
village supplies in..... 229–231
waterworks in..... 204, 219, 229
wells in..... 93, 203–231
records of..... 206, 213, 229
water of, analysis of..... 226
temperature in..... 16, 213
Grayling, wells at..... 331
Great Sable River, drainage by..... 89
Greenbush, springs near..... 266
wells at..... 266
Greendale Township (Midland County), wells in..... 243
wells in, location of, map showing..... 243
Greene Creek, well on..... 34
Greenleaf, wells at..... 249
Greenwood district, wells of..... 58–59
wells in, location of, map showing..... 58
Greenwood Township, wells in..... 111–112
Gregory, W. M., on Beulah and Benzonia wells..... 327–330
on Cheboygan County..... 355–368
on Frankfort area..... 330
on Geneva and Warren townships, Midland County..... 245–246
on Isabella County..... 92–111
on northwest border of Saginaw Bay. 269–271
on Ogemaw County..... 281–283
on Otsegama wells..... 297–301
work of..... 3, 231–[illegible]
Grindstone, wells at..... 269
Ground-water table, depth of..... 11–12
Grout Township (Gladwin County), wells in 114
Grove, wells near..... 63
Groveland Township (Genesee County), wells in, location of, map showing.... 174
Gustin, wells at..... 309
Gypsum, influence of, on water..... 14

H.

Haakwood, wells at..... 356–357
water of, analysis of..... 365
Hadley Township (Genesee County), wells in..... 173–175
wells in, location of, map showing..... 174
Hagensville, wells at..... 353
Hale, wells at..... 281
Hampton Township (Bay County), wells in..... 119–120

Page.
, waterworks at..... 259, 260, 263
's, wells at and near..... 365, 366-370, 375
d near, location of, map show-
:..... 367
of..... 368, 369
of, analyses of..... 369
at..... 296
s at..... 269
ls at..... 303
erworks at..... 112
rings near..... 308
cord of..... 308
..... 309
orks at..... 59, 62
ts at, water of, analysis of... 91
wells in..... 52-53
cation of, map showing..... 51
., spring in..... 181-182
..... 181-182
on of, map showing..... 182
of, analysis of..... 182
:, wells on..... 172
ils at..... 90
ghts, wells at..... 374
it, wells at..... 374, 375
ls at..... 75
at..... 353
it..... 260, 348
..... 22-23, 140-141
uses of..... 126-132, 208
ividual places.
stribution of..... 5
at..... 260
s at..... 306
, wells on..... 325
at..... 90
, springs on..... 88
ls in and near..... 62-65
ocation of, map showing..... 63
of, analysis of..... 91
, location of..... 305
erworks at..... 350
..... 350
nty, rainfall in..... 10
water of, temperature of..... 16
s at..... 303
it..... 130
r supply of..... 26
ship (Midland County), wells
i..... 237, 240-242
wells at..... 331
at..... 325-326, 331
:.. work of..... 3
wells at..... 346
ake, location of..... 305
..... 306
water supply of..... 62
rworks at..... 176
and near..... 176-179
on of, map showing..... 177
ds of..... 178
r of, analysis of..... 179
ke, location and drainage of... 307
..... 308, 351

Page.
Huber, wells at..... 75
Hudson, wells at..... 348
Hume Township (Huron County), wells in. 268
Hungerford, wells at..... 75
Huron, wells at..... 260
Huron, Lake, water of and from..... 257-258, 259
Huron County, flowing wells in..... 259, 261, 264-265, 268
map of part of..... 258
rainfall in..... 10
section across, figure showing..... 259
topography in..... 257-259
village supplies in..... 260
waterworks in..... 259-260
wells in..... 257-268
records of..... 261, 262, 264, 265
water of, temperature of..... 16, 264, 265
Huron Township (Huron County), wells in.. 268
Hydraulic ram, use of..... 126

I.

Ice ponds, use of well water for..... 125-126
Illinoian stage, drift of..... 8
Ina, wells at..... 90
Incrustation, chemical, description of and remedies for..... 128-130
Indian River, wells at and near..... 354, 355, 357-362, 366
wells at and near, location of, map showing..... 358, 371
water of, analyses of..... 361
Ingersoll district, wells of..... 240-242
wells of, contamination of..... 240
Ingersoll Township (Midland County), wells in..... 237, 240-242
wells in, location of, map showing..... 236
Ingham County rainfall in..... 10
wells in, water of, temperature of..... 16
Interlochen, wells at..... 315
Intermediate Lake district, wells in..... 335-338
Institutions, water supplies of..... 23-24
Intermediate Lake, wells on..... 8, 16
Ionia County rainfall in..... 10
wells in, water of, temperature of..... 16
Ioseo County flowing wells in. 269-270, 271, 274-279
maps of parts of..... 270, 275
rainfall in..... 10
topography in..... 269
waterworks in..... 269
wells in..... 269-270, 271, 274-281
records of..... 277
water of, analysis of..... 276
temperature of..... 16
Iron, presence of..... 14
Iroquois, location of..... 6
Ironton, wells at and near..... 340-341, 346
Irrigation, use of well water for..... 125
Isabella basin, wells in..... 93-94, 101-105
wells in, location of map showing..... 107
Isabella County, flowing wells in..... 92-109, 260
maps of parts of..... 95, 107
rainfall in..... 10
sections of, figures showing..... 92, 101, 106
topography of..... 92
waterworks in..... 109-110

rett, Frank, on M
pography
on Osceola County
on Osceola County
on Otsego County
on Presque Isle Cou
on Roscommon Cou
on Sanilac County
on Wexford County
work of
ring, wells at
is, S. J., work of
iston, waterworks a
wells at
ington, springs at
waterworks at
water of, analysi
wells at
y, location of, map
estone, water from
coln, wells at
coln River, drainage
coln Township (Hu
in
coln Township (New
in
den, wells at
kville, wells at
lefield, wells at
le Muskegon River, d
ingston, wells at
ingston County, flow
maps of parts of
rainfall in
spring in
topography of
waterworks in
wells in
records of
water of, analysis
temperature
g Rapids, wells at
tt, wells near
cas, wells at
ce, wells near
dington, waterworks a
wells at and near
pton, wells at and nea
ther, wells at
zerne, wells at

M

Bain, wells at and nea
Clure district, wells in
Kinley, wells at
Leans, wells at
Louth, C. D., on Mus
work of
ckinaw, water supply
comb County, rainfall
wells of, water of, to
agnetic Mineral Springs
altby, wells near
ancelona, waterworks
wells at

Page.
Isabella County, wells in..... 92-111
wells in, record of,..... 96,101-102,106,109
relations of, figure showing..... 106
water of, analysis of..... 109
temperature of..... 16
Isabella Township (Isabella County), wells in..... 93-94,101
Ithaca, wells at..... 229
Ivanhoe, wells at..... 260

J.

Jackson, water supply of..... 24
Jackson County, rainfall in..... 10
wells in, water of, temperature of..... 16
Jasper Township (Midland County), wells in..... 95,96,97-98,243-245
Jennings, waterworks at..... 305
wells at..... 305
Jewell, wells at..... 75
Johannesburg, wells near..... 348
Johnston, wells at..... 260
Judge, wells at..... 311
Juniata Township (Tuscola County), wells in..... 139

K.

Kalamazoo County, rainfall in..... 10
wells in, water of, temperature of..... 16
Kaleva, wells at and near..... 295,296-297
Kalkaska, waterworks at..... 313
wells at and near..... 312-313
Kalkaska County, description of..... 312-313
rainfall in..... 10
wells in..... 312-313
water of, analysis of..... 313
temperature of..... 16
Karlin, wells at..... 315
Kawkawlin River, valley of, wells in..... 115,116
Kawkawlin Township (Bay County), wells in..... 116,118,119
Kearney Township (Antrim County), wells in..... 336-337,338
Kent County, rainfall in..... 10
wells of..... 7
water of, temperature of..... 16
Killmaster, wells at..... 309
Kilmanagh, wells at..... 260
Kinde, wells at..... 260
Kingston, wells at..... 149 150
Kirk, wells at..... 74,75
Klondike, water supply of..... 62

L.

Lafayette Township (Gratiot County), wells in..... 203
Laing, wells at..... 249,257
Lake, wells at..... 75
Lake Ann, wells at..... 331
Lake City, waterworks at..... 305
wells at..... 305
Lake County, rainfall in..... 10
topography of..... 82-83
village supplies in..... 83
wells in..... 82-83
water of, temperature of..... 16
Lakefield Township (Saginaw County) wells in.....
Lake Harbor, water supply of.....
Lake Harbor district, topography of.....
wells of.....
Lakes, occurrence of.....
water supply from.....
Lakes, Glacial, description of.....
Laketon Township (Muskegon County), wells in.....
Lake Township (Huron County), wells in.....
La Motte Township (Sanilac County), wells in.....
Lane, A. C., on Huron County.....
on Saginaw water supply.....
work of..... 13,14,1
Lansing, water supply of.....
Lapeer County, flowing wells in.....
rainfall in.....
wells in.....
water of, temperature of.....
Larkin Township (Midland County), wells in.....
wells in, location of, map showing.....
Latitude, influence of, on temperature of underground water.....
Lattin, water supply of.....
Lattin district, wells of.....
Leaks, loss of head due to.....
Leelanau County, flowing wells in.....
rainfall in.....
topography of.....
village supplies in.....
wells in.....
water of, temperature of.....
Leeland Township (Leelanau County wells in.....
Leetsville, wells at.....
Legislation, character and text of.....
Leighton, M. O., analyses furnished by..... 182,185,186,226,237,248,303,313
Leland, wells at.....
Lenawee County, rainfall in.....
wells in, water of, temperature of.....
Le Rocque, wells at.....
Leroy, wells at.....
Leverett, Frank, introduction by.....
on Alcona County.....
on Alpena County.....
on Antrim and Charlevoix counties.
on Benzie County.....
on Cheboygan County.....
on Clare County.....
on Crawford County.....
on Emmet County.....
on Gladwin County.....
on Grand Traverse County.....
on Isabella County.....
on Kalkaska County.....
on Lake County.....
on Leelanau County.....
on Manistee County.....
on Mason County.....
on Midland County.....
on Missaukee County.....
on Montmorency County.....

Page.
on Muskegon County to-
phy..... 25
unty..... 83-84
unty..... 310
unty..... 347-349
le County..... 352-353
on County..... 305-306
unty..... 246-257
ounty..... 301-303
..... 3
..... 365
of..... 3, 14
orks at..... 350
..... 349, 350
gs at..... 251
t..... 247-248
analysis of..... 248
..... 249-252
f, map showing..... 250
..... 75
from..... 7
..... 308, 309
ainage of..... 80
p (Huron County), wells
..... 267
p (Newaygo County), wells
..... 74
..... 171
t..... 260
at..... 365
River, drainage of..... 75
at..... 348
ty, flowing wells in.. 125, 176-182
s of..... 177, 180, 182
..... 10
..... 181-182
f..... 175-176
n..... 176
..... 175-182
f..... 178, 181
analysis of..... 179, 182
erature of..... 16
ells at..... 351
..... 307
..... 305
..... 197, 199
rworks at..... 81
near..... 80, 82
and near..... 282, 289
..... 83
t..... 310

M.

and near..... 304, 305
, wells in..... 114-115
at..... 310
at..... 75
on Muskegon County..... 25-45
..... 3
r supply at..... 365
, rainfall in..... 10
ter of, temperature of..... 16
al Spring, character of..... 219
ar..... 289
erworks at..... 344
..... 345

Page.
Manistee, waterworks at..... 294-295
wells at..... 294
water of, analysis of..... 294-295
Manistee County flowing wells in..... 296-301
map of part of..... 297
rainfall in..... 10
topography of..... 294
village supplies in..... 295-296
waterworks in..... 294-295
wells in..... 293-301
record of..... 296, 300, 301
water of, analyses of..... 294-295, 300
temperature of..... 16
Manistee River, drainage of..... 83, 293, 301-302, 303-304, 311, 312, 334
wells on..... 293, 313
Manton, waterworks at..... 302, 303
wells at..... 303
Map, showing area discussed..... 2
showing artesian areas..... 6
showing contours..... 8
showing flowing-well temperatures..... 17
showing geology..... 8
Maple City, wells at..... 333
Maple Forest Township (Crawford County), wells in..... 311
Maple Ridge, wells at..... 281
Maple Ridge Park, wells in and near..... 183-184
wells in and near, location of, maps showing..... 184
Maple River drainage of..... 202
wells on..... 224
Maple River Township (Emmet County), wells in..... 364
Marion, wells at..... 84, 88, 90
Marion Township (Saginaw County), wells in..... 197, 198
Marlette, waterworks at..... 247
wells at..... 249
Marlette moraine, location of..... 246
Marls, water from..... 7-8
Marshall sandstone, water from..... 7, 121, 138, 232, 257, 258, 264, 266
See also Upper Marshall sandstone.
Mason County flowing wells in..... 80-81
map of part of..... 80
rainfall in..... 10
topography of..... 80
village supplies in..... 82
waterworks in..... 81
wells in..... 80-82
water of, temperature of..... 16
Maumee, Lake, location and history of..... 6
Mayfield, wells at..... 315
Mayville, wells near..... 144, 150
Meade Township (Huron County), wells in. 267
Mears, water supply of..... 62
Mecosta, well at..... 78, 79
well at, water of, analysis of..... 91
Mecosta County, flowing wells in..... 76-78
maps of parts of..... 76, 80
rainfall in..... 10
topography of..... 75-76
village supplies in..... 79
waterworks in..... 78-79
wells in..... 76-79

Page

Mecosta County, wells in, record of..... 78
water of, analyses of..... 90
temperature of..... 16, 78
Melita, wells at..... 281
Melvin, wells at..... 249
Merrill, wells at and near..... 197
Merritt Township (Bay County), wells in. 118, 120
Metz, wells at..... 353
Michigan, Lake, water supply near..... 12, 26
Michigan formation, occurrence of..... 261, 265, 266, 285
water in..... 271
Middleton, wells on..... 230
Midland, waterworks at..... 235
wells in and near..... 235–239
location of, map showing..... 236
record of..... 238
water of, analysis of..... 237
Midland County, flowing wells in. 125, 232–246, 269
map of part of..... 95, 233, 236, 243
rainfall in..... 10
topography of..... 232, 234
waterworks in..... 235
wells in..... 93, 96–98, 102, 131, 232–246
record of..... 238
water of, analysis of..... 237
character of..... 132
temperature of..... 16
Midland Township (Midland County), wells in..... 234–239
wells in, location of, map showing..... 236
record of..... 238
water of, analysis of..... 237
Mikado, wells at..... 309
Millbrook wells at..... 78, 79
Millersburg, water supply at..... 353
Millerton, wells at..... 80, 82
Millington, wells near..... 150–151
Minden, well at and near..... 249, 257
Mio, waterworks at..... 310
wells at..... 310
Missaukee County flowing wells in..... 304
rainfall in..... 10
topography of..... 303
village supplies in..... 305
waterworks in..... 305
wells in..... 303–305
water of, temperature of..... 16
Mitchie Creek, wells on..... 117
Moltke Township (Presque Isle County), wells in..... 352
Monitor Township (Bay County), wells in..... 115–116, 119
Monroe Center, wells at..... 315
Monroe County, rainfall in.....
wells of water of, temperature of..... 16
Montague, waterworks at..... 25, 26
wells at..... 28–31, 44
record of..... 28
water of, analysis of..... 37
Montague Township (Muskegon County), wells in..... 43–45
Montcalm County, rainfall in..... 10
wells in, water of, temperature of..... 16
Montmorency County, description of..... 349–350
wells in..... 349–350
Montrose, wells in and near.....
wells in and near, location of, map showing.....
Montrose Township (Genesee County, wells in.....
Moores Junction, wells at.....
Moore Township (Sanilac County), wells in..... 2
Moorland district, topography of.....
wells of..... 40–41,
gas in.....
Moorland Township (Muskegon County), well of..... 4
Moraines, character and distribution of..... 4
See also Topography
Morley, wells at..... 7
Mount Forest Township (Bay County), wells in..... 117, 11
Mount Haley Township (Midland County), wells in..... 237, 2
Mount Pleasant, waterworks at..... 109–11
wells at..... 92, 109–111, 2
records of..... 110, 11
Mullet Lake, wells near... 354, 355–356, 363, 3
Mundy Township (Genesee County), wells in..... 169–17
wells in, location of, map showing..... 16
Municipalities, water supplies of..... 2
Muskegon, waterworks at..... 2
wells at and near..... 32–37,
records of..... 32, 33,
water of, analyses of..... 36, 37
Muskegon County, flowing wells in..... 26–
lakes of..... 27
rainfall in..... 1
topography of..... 2
village supplies in..... 2
waterworks in..... 25–2
wells in..... 25–4
records of..... 28, 32, 33, 34, 39,
water of, analyses of..... 36, 37, 39
temperature of..... 16
Muskegon Lake district, topography of. 27, 31–
wells of..... 32–37,
head of..... 34–
water of..... 36–
Muskegon River, source, course, and drainage of..... 5, 25, 62, 75, 83,
wells on.....
Muskegon Township, Muskegon County, wells in.....

N.

Napoleon sandstone. *See* Upper Marshall sandstone.
Nellist, J. F., work of..... 3
Newark, wells at..... 230
Newaygo, waterworks at..... 72
waterworks at, location of, figure showing..... 70
wells in and near..... 62, 70–72, 75
location of, map showing..... 70
water of, analysis of..... 91
Newaygo County, flowing wells in..... 62–74
maps of parts of..... 63, 65, 69, 70, 73

Page.
Newaygo County, rainfall in..... 10
topography of..... 62
village supplies in..... 75
waterworks in..... 66, 72
wells in..... 62-75
records of..... 73
water of, analysis of..... 91
temperature of..... 16
Nessen City, wells at..... 331
New Era, water supply of..... 62
New Haven, wells at..... 230
Nipissing, Lake, location of..... 6
Nipissing beach, location of..... 6
Nirvana, wells at..... 83
No-che-mo Springs, location and description of..... 88-90
water of, analysis of..... 89
North Burns, wells at..... 260
North Muskegon, waterworks at..... 25, 26
well at, record of..... 33
Northport, wells at..... 333
North Shade Township (Gratiot County), wells in..... 231
North Star, wells at..... 230
Norton Township (Muskegon County), wells in..... 45
Norwood, wells at and near..... 339, 346
Ottawa basin, wells in..... 93, 95, 105-108
wells in, record of..... 105
Ottawa Township (Isabella County), wells in..... 92-93, 108

O.

Oak Grove, wells near..... 180-181
wells near, record of..... 181
Oak Grove Sanitarium, well at..... 159
well at, record of..... 159
water of, analysis of..... 159
Oakland County, flowing wells in..... 125
rainfall in..... 10
wells of, water of, temperature of..... 16
Obstructions, loss of head due to..... 128
Oceana County, flowing wells of..... 46-59
maps of parts of 46, 49, 51, 54, 55, 56, 57, 58
rainfall in..... 10
topography of..... 46
village supplies in..... 62
waterworks in..... 50-61
wells in..... 46-62
water of, analyses of..... 91
temperature of..... 16
Oden, section at, figure showing..... 373
wells at and near..... 365, 366, 371-377
location of, map showing..... 372
water of, analysis of..... 375
Ogemaw County, flowing wells in..... 269, 281-293
maps of parts of 283, 289
section of, figure showing..... 290
rainfall in..... 10
springs in..... 282-283
topography of..... 281
village supplies and waterworks in..... 282
wells in..... 281-293
records of..... 286, 287
water of, temperature of..... 16, 285, 292
Ola, wells at..... 230
Old Mission, wells at..... 315
Oliver Township (Huron County), wells in..... 264-265
Omena, wells at..... 333
Omer, wells at..... 271, 281
Onaway, waterworks at..... 353
wells at..... 353
Onekama, wells at..... 294, 295, 297-301
wells in, location of, map showing..... 297
records of..... 300, 301
water of, analyses of..... 300
Orient, wells at..... 90
Orono, wells at..... 90
Ortonville area, wells of..... 128
wells in, location of, map showing..... 174
Osceola County, elevations in..... 5, 83
flowing wells in..... 85-88
map of part of..... 85
rainfall in..... 10
springs in..... 88-90
water of, analysis of..... 89
village supplies in..... 90
waterworks in..... 84-85
wells in..... 83-88, 90
water of, analyses of..... 90
temperature of..... 10
Osceola Spring, character of..... 90
Oscoda, waterworks at..... 269, 281
Oscoda County, description of..... 310
rainfall in..... 10
waterworks in..... 310
wells in..... 310
water of, temperature of..... 16
Ossineke, water supplies at..... 351
Otia, wells at..... 75
Otisville district, wells of..... 156
Otsego County, rainfall in..... 10
springs in..... 348
topography of..... 347
waterworks in..... 349
wells in..... 347-348
water of, temperature of..... 16
Otsego Lake, wells on..... 348
Ottawa County, rainfall in..... 10
wells of..... 7
water of, temperature of..... 16
Otterburn, wells at..... 160
Overdevelopment, loss of head from 126-127
Owendale, wells at..... 260
Owosso, springs at..... 185-186
waterworks at..... 186
wells at..... 130, 183-185
location of, maps showing..... 184, 186
records of..... 186-190
water of, analysis of..... 185

P.

Palms, wells at..... 249
Paris, wells at..... 78, 79
Paris Township (Huron County), wells in. 259, 263
Parisville, wells at..... 260
Park Lake, wells at..... 90
Parks, wells at..... 75
Pawlowski, wells at..... 260

Page

Peachville, water supply of 62
Peck district, wells in 253-254
Pellston, wells at 365
Peninsula Township (Grand Traverse County), wells in 314
Pentwater, waterworks at 60-61, 62
waterworks at, water of analysis of 91
Pentwater River, drainage by 46
Pentwater Township, wells of 80-81
wells of, location of, map showing 80
water of, analysis of 91
Pere Marquette River drainage by 46, 80
Perrinton, wells at 231
Petoskey wells at 365
Phelps wells at 346
Pierport, wells at 295
Pigeon, wells at and near 258, 260, 265
Pigeon River, drainage of 347
Pinckney wells near 179
Pinconning, wells at 269, 270-271
wells at, location of, map showing 270
Pinconning Township (Bay County), wells in 117, 119, 269, 270-271
Pine Creek, wells on 231
Pine Lake, wells on 8, 340, 341
Pine River, drainage of 92, 202, 307
spring on 109
water from 204
wells on and near .. 212, 215, 221-223, 229, 230, 308
Pine River (post-office), wells at 281
Pine River Township (Gratiot County), wells in 215-216
wells in, location of, maps showing 215, 216
Pine Run, wells on 156
Pinnibog, wells at 260
Pionee wells at 305
Platte, wells at 331
Platte River, drainage of 324
wells on 325
Pleasant View, wells at 365
Pogy, wells at 79
Pointe aux Barques, wells at 260
Points well, clogging of 128-130
description of 128
use of 13
Pompeii, wells at 231
Ponshewaing, wells at 372, 374-375, 377
wells at, record of 377
Popple, wells at 260
Population, estimates of 4, 23-24
Portage Lake, character of 297
well on 293-294, 299
Port Austin, water supply at 260
Port Austin Township (Huron County), wells in 268
Port Crescent, wells at 260
Port Hope, water supply at 260
Port Huron, rainfall at and near 11
Port Sanilac, wells at and near 249, 255-256
Portsmouth Township Bay County), wells in 118, 120
Posen, wells at 353
Precipitation, records of 10-11
Prescott, wells at 282
Presque Isle County, rainfall in 10

Page

Presque Isle County, topography of ..... [illegible]
village supplies and waterworks in ..... [illegible]
wells in ..... [illegible]
water of, temperature of ..... [illegible]
Provement, wells at ..... [illegible]
Prudenville, wells at ..... [illegible]

R.

Rainfall, records of 10-11
Rainy River, drainage of ..... [illegible]
Rams, hydraulic, use of ..... [illegible]
Rapid City wells at ..... [illegible]
Rapson, wells at ..... [illegible]
Rathbone, wells at ..... [illegible]
Ravenna, water supply of ..... [illegible]
Reed City, springs near ..... [illegible]
springs near water of, analysis of ..... [illegible]
waterworks at ..... [illegible]
wells at ..... [illegible]
water of, analysis of ..... [illegible]
Redman, wells at ..... [illegible]
Redoak, wells at ..... [illegible]
Reeman, wells at ..... [illegible]
Reese, wells at ..... [illegible]
wells at, records of ..... [illegible]
Remus, wells at ..... [illegible]
Rescue, wells at ..... [illegible]
Rice Lake, wells on ..... [illegible]
Richfield Township (Genessee County), wells in ..... [illegible]
wells in, location of, map showing ..... [illegible]
Rifle River, wells on ..... [illegible]
Riverdale, waterworks at ..... [illegible]
wells in and near ..... [illegible]
record of ..... [illegible]
Rivers, course of ..... [illegible]
supply of ..... [illegible]
water supply from ..... [illegible]
Riverside Township (Missaukee County), wells in ..... [illegible]
Rock, water from, character of ..... 133-135, 137-138, 196-1[illegible]
Rodney, wells at ..... [illegible]
Rogers, wells at ..... [illegible]
Rondo, wells at ..... [illegible]
Roscommon, population of ..... [illegible]
waterworks at ..... [illegible]
wells at ..... [illegible]
Roscommon County, flowing wells in ..... [illegible]
rainfall in ..... [illegible]
topography of ..... [illegible]
waterworks in ..... [illegible]
wells in ..... 305-3[illegible]
water of, temperature of ..... [illegible]
Rose City wells at and near ..... 269, 281, 288-[illegible]
Rose Lake, wells at ..... 84, 8[illegible]
Rothbury, water supply of ..... [illegible]
Rubicon Township (Huron County), wells in ..... [illegible]
Russell, T., on Michigan weather ..... [illegible]
Ruth, wells at ..... [illegible]

S.

Saganing, wells at ..... [illegible]
Saganing Creek, wells on ..... [illegible]
Sage Township (Gladwin County), wells in. [illegible]

Page.
'orks at..... 201
..... 195, 202
ocation of..... 6
ainage basin of, counties in 121
in of, physiography of .. 121-124
plies of..... 121-246
ty of..... 132-133
of, loss of loss..... 126-131
ypes of..... 124-125
ation of..... 125-126
of, map of..... 270
rder of, wells on..... 269-281
of..... 120
..... 120-121
near, head in..... 23
flowing wells in..... 125, 196-201
..... 10
of..... 194
n..... 201
..... 194-202
analysis of..... 201
eter of..... 195
erature of..... 16
scription and location of .. 4-5
haracter of..... 202
ainage of..... 194
ells on..... 7
rainfall in..... 10
r of, temperature of..... 16
ells on..... 7
t..... 306
at..... 346
y, rainfall in..... 10
r of, temperature of..... 16
vorks at..... 219
..... 127, 130, 203, 219-220
..... 220
age of..... 92
..... 14
ence of..... 196, 294
, relation of water supply
..... 9
gging by, loss of head due to 128
wnship (Huron County),
in..... 263
rence of..... 5
from..... 7
..... 79
aterworks at..... 248
..... 249, 256
lowing wells in..... 249-257
of..... 250
..... 10
..... 251, 252
of..... 246-247
es in..... 248-249
n..... 247-248
..... 247-257
analyses of..... 248
erature of..... 16, 250, 251, 252
p (Sanilac County), wells
..... 255-256
ater, analyses of..... 363
works at..... 81
..... 82

Page.
Sears, wells at..... 90
Sebewaing, coal mines at, subdrainage by.. 140
wells at..... 260
Sebewaing Township (Huron County), wells
in..... 260-261
wells in, record of..... 261
Seville Township (Gratiot County), wells
in..... 213-215
Sharon, wells at..... 313
Shaw, wells at..... 75
Shelby, waterworks at..... 60, 62
waterworks at, water of, analysis of ... 91
Shelby district, section across, figure showing..... 51
wells of..... 49-51
location of, map showing..... 49
water of, analysis of..... 91
Sheridan Township (Clare County), wells
in..... 113
Sheridan Township (Huron County), wells
in..... 259, 262-263
Sheridan Township (Mecosta County), wells
in..... 77-78
water of, analysis of..... 91
Sheridan Township (Newaygo County),
wells in..... 74
Sherman, wells at..... 303
Sherman Township (Huron County), wells
in..... 263
Sherman Township (Newaygo County),
wells in..... 74
Sherman Township (Osceola County), wells
in..... 83-84
Sherzer, W. H., work of..... 3
Shiawassee County, flowing wells in..... 125, 183-186, 191-192
maps of parts of..... 184, 186, 191
rainfall in..... 10
springs in..... 185-186
topography of..... 183
waterworks in..... 186, 193
wells of, records of..... 186-190
wells in..... 183-193
water of, analysis of..... 185
temperature of..... 16, 193
Shiawassee River, drainage of..... 175, 181, 183, 191-192, 202
wells on..... 171
Sigel, wells at..... 260
Sigel Township (Huron County), wells in... 264
Siloam, wells at..... 281
Silt and sand, clogging by, loss of head due to..... 128
Silverwood, wells at..... 154-155
Simmons, wells at..... 345
Slocum, water supply of..... 26
Snoover field, wells in..... 256-257
Soils, buried, occurrence of..... 8
Solon, wells at..... 333
South Arm, wells at..... 8, 340
water of, analysis of..... 340
South Boardman, wells at..... 313
South Branch, wells at..... 282
South Frankfort, wells at..... 331
South Pere Marquette River, drainage of.. 62

Page.
Speaker Township (Sanilac County), wells in 253
Spencer, wells at 313
Springfield Township (Kalkaska County), wells in 312
Spring Lake district, topography of 27, 39
wells of 39-40, 42
records of 39, 40
water of, analysis of 39
Springport, springs near 308
wells near 309
Springvale, wells at 346
Springwater Siding, springs near 343
wells at and near 343
Spruce, wells at 309
Standish, waterworks at 269
wells at 269, 271, 281
Stanwood, wells at 79
Star, wells at 348
Stimson, wells at 79
Stittsville, wells at 305
Strainer, clogging of, loss of head due to .. 128-130
Stratford, wells at 305
Streams. *See* Rivers.
Sturgeon River, drainage of 347
Sullivan, water supply of 26
Sulphates, presence of 14
Summit City, wells at 315
Summit Townsh p (Mason County), wells of 80-81
wells in, location of, map showing 80
water of, analysis of 91
Suttons Bay, wells at 333
Swan Creek area, wells in 197, 199
Swartz Creek, wells in 168
Sylvania sandstone, water from 7

T.

Tallman, wells at 80, 82
Tanks, use of 196
Tanner, wells at 295
Tawas, wells at 269, 270, 274-279
wells at, location of, map showing 275
records of 277
water of, analyses of 276
Temperatures of water, map showing 17
of water and air, records of 14-20
Temple, wells at 112
Thompsonville, waterworks at 331
wells at 325, 331
Thumb Lake, wells at 346
Thunder Bay River, drainage of .. 307, 349, 350, 352
water from 350
Tigris, water supply of 62
Tigris district, wells of 55-56
wells in, location of, map showing 56
Tittabawassee River, water from 121
wells on 113, 115, 232
Titus, wells at 79
Topinabee, wells at 366
Topography, outline of 4-6
See also individual counties.
Torch Lake, wells near 313, 345
Traverse City, wells at and near 16
312, 315, 319-324
wells at and near, records of 322, 323
water of, analyses of 321-322

Page.
Trowbridge, wells at ..... [illegible]
Troy district, flowing wells in ..... [illegible]
Tubular wells, description of ..... [illegible]
utilization of ..... [illegible]
Turner, flowing well at, view of ..... [illegible]
wells at ..... [illegible]
Tuscola, wells at ..... [illegible]
Tuscola County, drift waters in .. 136-137, [illegible]
flowing wells in ..... 125, 139-142, [illegible]
rock waters in ..... [illegible]
rainfall in ..... [illegible]
springs in ..... [illegible]
surface waters in ..... [illegible]
topography of ..... 133-135, 142-143, [illegible]
village supplies in ..... [illegible]
wells in ..... 134, [illegible]
records of ..... 144, 147, [illegible]
water of, analysis of ..... [illegible]
character of ..... [illegible]
temperature of ..... [illegible]
Tustin, wells at ..... [illegible]
Twining, wells at ..... 270, 271-[illegible]
wells at, location of, map showing ..... [illegible]
Twin Lakes, wells on ..... [illegible]
Typhoid fever, occurrence of ..... [illegible]

U.

Ubly, wells at ..... [illegible]
Udden, J. A., work of ..... [illegible]
Unionville, wells at and near ..... 141-142, [illegible]
Upper Marshall sandstone, map showing elevation of ..... [illegible]
salt in ..... [illegible]
water in ..... 258, 261, [illegible]

V.

Valentine Lake, wells at ..... [illegible]
Valley Center, wells near ..... [illegible]
Van Buren County, rainfall in ..... [illegible]
wells of, water of, temperature of ..... [illegible]
Vanderbilt, wells near ..... [illegible]
Vassar, wells at and near ..... 134, 146, 153-[illegible]
wells at and near, water of, analysis of. [illegible]
Vaughn, wells at ..... [illegible]
Vaughan, V. C., work of ..... [illegible]
Vernon, wells in and near 192-193
Vernon Township (Isabella County), wells in ..... 93, 102, 105, 106, [illegible]
well in, record of ..... [illegible]
Verona Township (Shiawassee County), wells in 192-193
Verona Township (Huron County), wells in ..... 259, [illegible]
wells in, record of ..... [illegible]
Vienna, wells at ..... [illegible]
Volney, wells at 74, 75

W.

Wadsworth, wells at ..... [illegible]
Wagar, water supply of ..... [illegible]
Walkerville, water supply of ..... [illegible]
Walloon Lake, wells on 343-344
Walton, wells at 314
Warren, Lake, location of 6
Warren Township (Isabelle County), wells in 93

Page.
ship (Midland County), wells 245-246
Township (Gratiot County), ells in..... 227
ounty, rainfall in..... 10
ater of, temperature of..... 16
head due to..... 126-127, 207-208
of..... 13, 21-22, 127, 208
disposal of..... 196
ground, occurrence of..... 7-8
e of, map showing..... 6
..... 14
ires of..... 14-20
howing..... 17
g formations, distribution of.. 7-8
use of..... 126
Township (Tuscola County), ells of..... 143, 144
statistics of..... 23-24
ls at and near..... 7
y, rainfall in..... 10
..... 7
of, temperature in..... 16
t, wells of..... 56-37
cation of, map showing..... 57
of, analysis of..... 91
au, United States, records of. 10-11
at..... 79
ong well, water of, analysis of. 318
ells at..... 311
See Points, well.
tion of..... 12-13
, loss of, causes of..... 126-132
..... 124-125
temperature of..... 16
rature of, map showing..... 17
ply from..... 24
dividual counties.
g, occurrence of..... 364
of..... 9, 22
..... 23
n of, explanation of..... 122-123
f..... 22
..... 22-23
..... 126-132
of..... 8
ires of, map showing..... 17
..... 22
n..... 13, 21-22
ply from..... 24
dividual counties.
currence of..... 196, 294
ip (Tuscola County), wells in. 143, 144-145
g, wells at..... 365, 366-370
y, waterworks of..... 120

Page.
West Branch waterworks at..... 282
wells at and near..... 281, 282-288
location of, map showing..... 283
records of..... 286, 287
Westwood, wells at..... 313
Wexford, wells at..... 303
Wexford County, rainfall in..... 10
topography of..... 301
village supplies in..... 303
waterworks in..... 302
wells in..... 301-303
water of, analyses of..... 303
temperature of..... 16
Wheeler, wells at and near..... 231
Whitecloud, wells at..... 75
Whitehall, waterworks at..... 25-26
wells at..... 28-31, 43-45
record of..... 28
White Lake, water from..... 25-26
White Lake district, topography of..... 27
wells of..... 28-31, 42
White River, source and course of.... 25, 27, 46, 62
wells on..... 63
White River Township (Muskegon County), wells in..... 43
Whiterock Township (Huron County), wells in..... 263
Whittemore, wells at..... 281
Whittlesey, Lake, location of..... 6
Wickware, wells at..... 249
Williamsburg district, sections through.. 317, 318
wells in..... 16, 312, 315-319
location of, map showing..... 316
water of, analyses of..... 318
Williams Township (Bay County), wells in.. 115-116, 118, 119
Wilmot, wells at..... 154
Wilson, wells at..... 348
Windmills, use of..... 13
Winsor Township (Huron County), wells in. 259, 265-266
wells in, record of..... 265
Wisconsin stage, drift of..... 8
Wise Township (Isabella County), wells in.. 93, 102, 105
Wisner Township (Tuscola County), deer licks in..... 138
wells in..... 139
Wolverine, wells at..... 355
Woodville, wells at..... 75
Wooster, wells at..... 74, 75
Wurzel Saginaw Magnetic Mineral Spring, character of..... 200-201
water of, analysis of..... 201

Y.

Yuma, wells at..... 303

ASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 183.]

The serial publications of the United States Geological Survey consist of (1) Annual ports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral sources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United ates—folios and separate sheets thereof, (8) Geologic Atlas of the United States—ios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the hers are distributed free. A circular giving complete lists can be had on application. Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they n be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for stribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, . C., from whom they can be had at practically cost.
4. Copies of all Government publications are furnished to the principal public raries in the large cities thruout the United States, where they can be consulted those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of bjects, and the total number issued is large. They have therefore been classified o the following series: A, Economic geology; B, Descriptive geology; C, Systemc geology and paleontology; D, Petrography and mineralogy; E, Chemistry and ysics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water stor-e; K, Pumping water; L, Quality of water; M, General hydrographic investigans; N, Water power; O, Underground waters; P, Hydrographic progress reports. is paper is the sixty-third in Series O, the complete list of which follows (PP=Prosional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES O, UNDERGROUND WATERS.

4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)
6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)
7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)
12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)
21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls. (Out of stock.)
26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp. (Out of stock.)
30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls. (Out of stock.)
31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)
34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.
53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)
54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp. (Out of stock.)

WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1902. 68 pp., 7 pls. (Out of stock.)

WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)

WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)

WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96–140 pp. (Out of stock.)

WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)

WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. (Out of stock.)

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.

WS 78. Preliminary report on artesian basin in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.

WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.

WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.

WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.

WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls. (Out of stock.)

WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.

WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.

WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.

WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

WS 149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls.

3. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.
4. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.
5. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906. 83 pp., 9 pls.
7. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.
8. Preliminary report on the geology and underground waters of the Roswell artesian area New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.
. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.
9. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson, 1906. 86 pp., 6 pls.
. Geology and water resources of the Bighorn basin, Wyoming, by C. A. Fisher. 1906. 72 pp., 16 pls.
50. Underground-water papers, 1906, by M. L. Fuller. 1906. 104 pp., 1 pl.
53. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp.
54. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.
81. Geology and water resources of Owens Valley, California, by Willis T. Lee. 1906. 28 pp., 6 pls.
82. Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 292 pp., 5 pls.
83. Flowing wells and municipal water supplies in the middle and northern portions of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 393 pp., 5 pls.

e following papers also relate to this subject: Underground waters of Arkansas Valley in eastern ado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a on of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, ank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank rett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward , in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by Darton, Bulletin No. 138.

rrespondence should be addrest to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

VEMBER, 1906.

O

Water-Supply and Irrigation Paper No. 184

Series { K, Pumping Water, 13
O, Underground Waters, 65

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE UNDERFLOW

OF THE

SOUTH PLATTE VALLEY

BY

CHARLES S. SLICHTER AND HENRY C. WOLFF

WASHINGTON

GOVERNMENT PRINTING OFFICE

1906

CONTENTS.

	Page.
ation and purpose of the investigations	5
ter-bearing gravels	6
ıditions at Sterling, Colo	8
estigations at Ogalalla, Nebr	9
Velocity and direction of the underflow	9
Quantity of the underflow	12
Chemical analyses of water	12
Underflow ditch at Ogalalla	15
Disadvantages of underflow canals	22
estigations at North Platte, Nebr	23
Slope of the water plane	23
North Platte city waterworks pumping plant	25
Springs and artesian water of Birdwood Creek	26
gestions for the construction of small pumping plants	29
Kind of wells adapted to the South Platte gravels	29
Amount of water that can be obtained	29
Distance between wells	30
Kind of pump	33
Method of priming pumps	34
Pipe fittings	34
Source of power	35
Economical distance water may be lifted	35
Storage reservoirs	35
Cost of pumping	36
pendix	38
lex	41

ILLUSTRATIONS.

Page.

FIG. 1. Cross section of South Platte Valley at Ogalalla, Nebr. 10
2. Map of Hollingsworth underflow ditch, Ogalalla, Nebr. 17
3. Diagram showing discharge over weirs Nos. 1, 2, and 3 in the Hollingsworth underflow ditch and the elevation of the water in the river between August 6 and 21, 1905 18
4. Diagram showing discharge of Hollingsworth underflow ditch from 8 a. m. August 20 to 3 p. m. August 21, 1905 19
5. Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 24, 1905 19
6. Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 27 and 28, 1905 20
7. Profile of water plane at line of test wells near the head of the Hollingsworth underflow ditch 21
8. Diagram showing change in elevation of the ground water at North Platte, Nebr., between 1890 and 1905 24
9. Map of city waterworks pumping plant at North Platte, Nebr. 26
10. Diagram showing the position of the water plane and the coarse water-bearing gravel near the head of West Birdwood Creek 28
11. Diagram of a pumping plant in the Arkansas Valley for recovering water from a dug well provided with seven galvanized-iron strainers or feeders 31
12. Suggested arrangement of wells and pump for a plant designed to recover 2,500 gallons of water per minute 32
13. Diagram showing relative shape of standard and "long sweep" pipe fittings 35

'HE UNDERFLOW OF THE SOUTH PLATTE VALLEY.

By C. S. SLICHTER and H. C. WOLFF.

LOCATION AND PURPOSE OF THE INVESTIGATIONS.

Investigations were begun in the middle of July, 1905, in that part the South Platte Valley extending from Sterling, Colo., to North atte, Nebr. The purpose of the survey was to determine what ources, if any, existed in the underflow waters of the valley and ıether it was practicable to make use of such waters, if they were und to exist in suitable quantities, for purposes of irrigation.

The greater part of the work was carried on at Ogalalla, Nebr. ıis point was selected for several reasons; primarily for the fact that ı underflow canal on the south side of the river at this place has been successful operation for several years and has attracted the atten- ɔn of those interested in irrigating the bottom lands of the valley. was thought that valuable information might be obtained from ɔservations on the operation of this canal, concerning not only the 'acticability of recovering ground water by the gravity method, but so the extent of the deposits of water-bearing gravels and the ease ith which they yield water under small heads. Again, while the ɔnditions found existing at this point are probably not in all respects 'pical for the valley in western Nebraska, the results obtained can ɔ applied to any part of the valley.

In the eastern part of Colorado and in the western part of Nebraska ıe South Platte Valley ranges from 6 to 8 miles in width. Near galalla it narrows down to about 2 miles and holds approximately is width to Sutherland, Nebr., a distance of about 32 miles. Below ıtherland the valleys of South Platte and North Platte rivers unite d form a broad, low tract of land west of the city of North Platte. From Sterling, Colo., to Ogalalla the direction of the South Platte lley is about N. 80° E.; from Ogalalla to North Platte the direc- n is almost due east.

In western Nebraska the river has cut to a depth of 150 to 300 feet the Ogalalla formation, with steep bluffs on the north side, but h more gentle slopes rising to the rolling uplands on the south. e Ogalalla formation is a deposit of sand, gravel, and calcareous

grit, from which the river sands were, for the most part, derived by the washing out of the fine sand, silt, and cementing material.

Lodgepole Creek, the only tributary of any size, joins the South Platte from the west near the Colorado-Nebraska State line. This stream has cut down into the Brule clay and is fed by spring water from the overlying Ogalalla formation. At places the surface flow is entirely taken out for purposes of irrigation.

The river itself occupies a sandy stretch from 1,500 to 2,500 feet in width. During low stages the river flows in this wide bed in numerous interlocking small streams, among which it is difficult to select the principal channel. Much of the bottom land near the river is low and swampy. These low bottoms vary greatly in width at different places, and at points where the width is considerable they leave but a small area of land suitable for irrigation. Above the bottom lands the valley slopes gently away from the channel, here and there in two or three distinct levels, but at many places in a gradual rise without noticeable benches, to the base of the escarpment that borders the uplands on either side of the river. The uplands or table-lands within which the river has cut its valley have the well-known level topography of the High Plains of western Kansas and Nebraska.

Numerous irrigation canals have been taken out of South Platte River at various points in Colorado and Nebraska. As a rule these canals carry water to the bottom lands only. At no place between Sterling and North Platte has it been practicable to construct a canal to convey water to the uplands, owing to their elevation. Where the irrigation systems have been properly constructed and maintained the results have been very satisfactory, except during the middle and end of the irrigating season, when the farmers complain of the shortage of water—a complaint frequently heard in irrigation districts. In order to augment the low-stage supply of water several reservoirs have been constructed in the South Platte Valley in Colo ado.

WATER-BEARING GRAVELS.

Inasmuch as irrigation must of necessity be confined to the bottom lands of the valley, it is especially important to know to what extent these lands can be irrigated by means of water drawn from the underflow of the river. This point was kept well in mind during the investigations.

The gradient of the river channel along this portion of its course averages about 8 feet to the mile. The alluvial deposits consist of a coarse sand, with which are mixed gravels of various sizes up to pebbles 1 inch in diameter. The larger pebbles are not deposited in separate streaks, but are scattered through and mixed with the coarse sand of the river deposits. In this respect the sands of the South Platte differ materially from the sands of Arkansas River in western

ansas, in which the larger pebbles are usually absent. Moreover, e South Platte sands are fairly free from deposits of quicksand and ıe silt.

The presence of the large pebbles in the coarse sands of the South atte deposits renders this material an excellent water-bearing avel, especially well adapted for the construction of wells of large pacity. By the use of proper strainers the smaller particles can be moved from the immediate neighborhood of a well, so that the water n be collected through the coarser material that is left. Gravel of is kind was found wherever sought between Sterling and North latte, and it is believed that there is no considerable area in this part the valley which is not underlain with similar gravel.

In order to determine the amount of water that can be obtained om such gravels by means of suitably constructed wells and pumpıg machinery, it was planned to test wherever practicable the capacity f existing wells in the valley. It was found, however, that so few umping plants had been constructed that it was not possible to get ›gether a very large amount of data bearing on this point; but ıch tests as could be made indicate that wells of high capacity can e very economically constructed and that no difficulty will be xperienced in the recovery of water in quantities suitable for rigation.

The reconnaissance work indicated that there is very little differnce in the water-bearing gravel between Sterling, Colo., and Ogalalla, Nebr. The valley varies considerably in width, but the water-bearing naterial seems to be fairly uniform.

From fig. 1 (p. 10) it will be seen that the river gravels are not very leep or extensive at Ogalalla; all the test wells, with one exception, vere driven completely through the deposit. At station 1, 200 feet outh of the north bank of the river, good water-bearing gravel was ound at a depth of 85 feet, where driving ceased. The average depth f the gravel between stations 9 and 4 was found to be about 40 feet. At the edges of the valley, beyond these stations, the gravels probably hin out very abruptly, for at the section line shown at the right of he figure and in the bluffs shown at the left appears the undisturbed ormation within which the valley is cut.

Fine material was encountered in but a single instance, about 200 eet south of the south bank of the river. This station was located in portion of the old river bed, now a swamp in process of being filled ıp by decaying vegetation, blowing sand, and silt deposited by the iver at times of flood. The upper 25 feet of sand within the river bed s very much cleaner and its effective size probably much greater than hat found elsewhere in this part of the valley. At a depth of about 25 feet there is a marked change, the sands below containing a slightly ncreased proportion of smaller grains, together with a very small

amount of argillaceous material. The line of separation of the upper from the lower sands is about on a level with the lower limit of the river deposits on either side of the channel. The origin of the two classes of deposits probably lies in part in the fact that the fine material brought in by the lateral component of the underflow works its way downward to the deep deposits by the constant subdivision and mingling of the water as it flows through the capillary spaces between the sand grains, and in part in the tendency of the ground water, which flows in from both sides, to come eventually to the surface and wash out and carry downstream with it a considerable amount of fine material. The gravels in all cases where test wells were put down have a sharply defined lower limit, resting upon a soft formation of sand (usually very fine) and calcareous grit. In places, however, the material is so firmly cemented that it offered considerable resistance to the driving of the test wells. This underlying material is practically impervious, as in only a few cases was it possible to draw water from it, and even then only with great difficulty.

CONDITIONS AT STERLING, COLO.

At Sterling the valley of the South Platte is very wide. A pumping plant constructed for the purpose of irrigation is located on the Johnson ranch, on the east side of the river. The dug well used in connection with this plant was so poorly sheeted up that large quantities of sand entered the pump, making the test unsatisfactory. It will be very easy, at small expense, to so modify the well that the sand will be kept away from the pump, after which there will be no difficulty about obtaining a large supply of water.

In the vicinity of Sterling the water-bearing gravels extend to a depth of 40 to 80 feet below the surface, and there is unquestionably an ample supply of water for a large number of moderate-sized pumping plants. It is believed that the best method of recovering the ground water at this point is by means of wells and pumping machinery, either owned by the individual farmers or operated by electricity from a central plant. Considerable interest is taken at the present time in this locality in the growing of sugar beets, and a large sugar factory has already been constructed. It may be practicable to distribute power from this factory during the irrigation season to a number of farmers who live in the neighborhood, for the purpose of procuring a sufficient supply of ground water for the irrigation of the beet and other crops suitable to this locality. It is not believed advisable to put in large pumping stations designed to take out large amount of ground water at any one place. It seems evident that it is more economical to restrict the amount of ground water taken out at any one place to about 2,500 gallons a minute, rather

an attempt to get a greater supply. A number of moderate-sized ants will be found to be much more economical and satisfactory the long run than a few large plants.

INVESTIGATIONS AT OGALALLA, NEBR.

VELOCITY AND DIRECTION OF THE UNDERFLOW.

At Ogalalla a series of test wells was sunk in a nearly north and uth line across the valley and careful determinations were made of e extent and quality of the water-bearing material and of the tual rate of movement of the underflow.

The rate of movement of the ground water was determined by the ectrical method.[a] The investigation showed that there is a true iderflow at this point, the ground waters moving downstream with velocity varying from 2.3 to 13.6 feet per twenty-four hours. The verage velocity of eight determinations was found to be 6.4 feet per venty-four hours, with an average direction of about N. 88° E. Fig. gives a cross section of the valley, looking downstream, showing the cation of the test wells, the extent of the alluvial deposits, and the osition of the water plane. The numbers within the circles give ie velocity of the underflow in feet per twenty-four hours at the arious stations for a depth corresponding to the position of the umbers. These velocities are also given in Table I. With the xception of the three highest velocities (13.6 and 12 feet per twenty-our hours, found near the surface of the river channel, and 9.2 feet er twenty-four hours, found at station 9) the rate was very uni-orm, ranging from 2.3 to 4.4 feet per day. The water-bearing ravels of this section may be classified with reference to velocities f underflow into four distinct portions—the portion north of the ver, within which the mean of the velocities was 6.8 feet per day; ie portion south of the river, within which the mean of the two elocity determinations gave 3.55 feet per day; the portion within ie river channel down to a depth of 25 feet, within which two tests ere made giving the two highest velocities; and the portion within e river channel below the 25-foot line, within which the remaining vo of the eight velocity determinations gave a mean flow of but 55 feet per day. From Table I it will be seen that the two veloci-es found within each section are nearly equal, but differ very much om velocities found in other sections. The lowest velocity was und at station 1, 85 feet below the river bed, the deepest point at hich a velocity test was made. The high velocities at the shallow epths within the river channel may be due to the fact that the sand the upper 25 feet is exceedingly clean and contains practically o very fine material.

[a] Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 17-31.

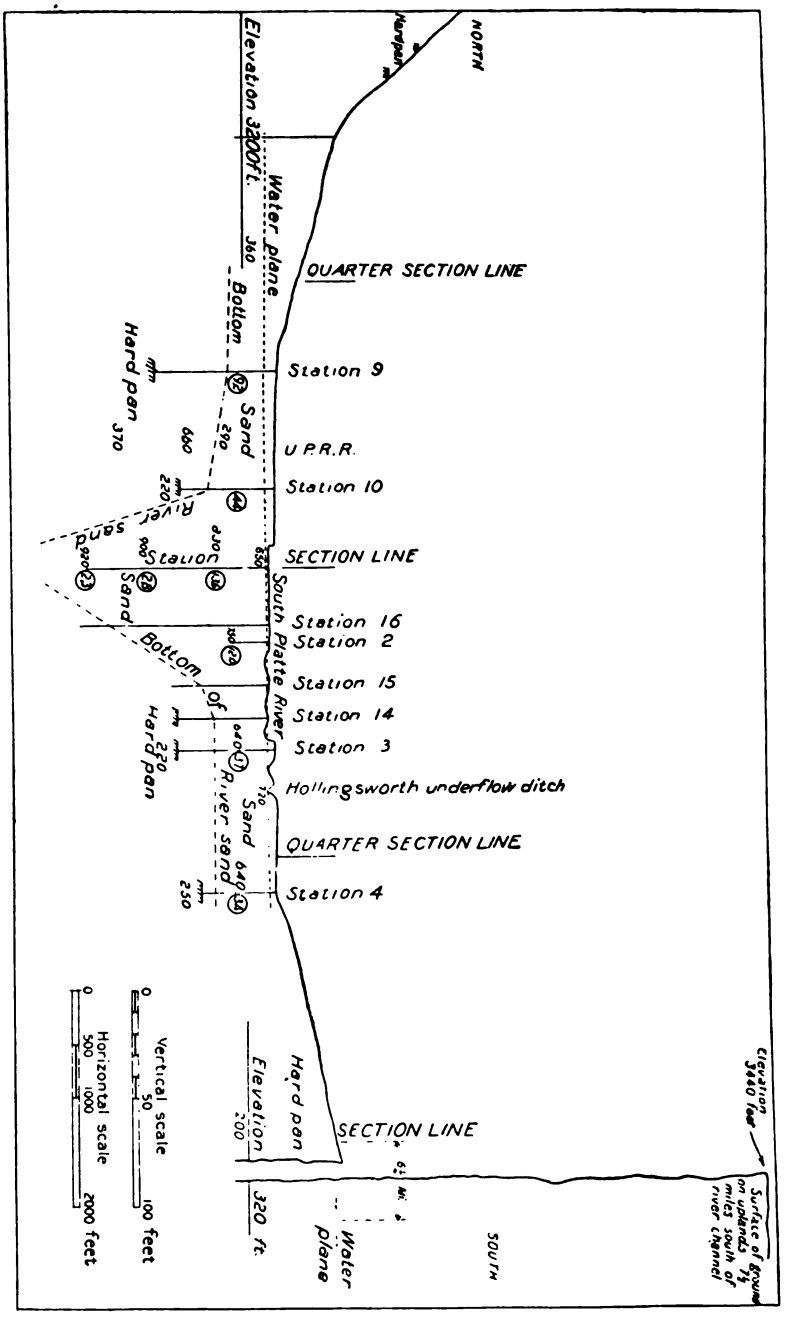


FIG. 1.—Cross section of the South Platte Valley at Ogalalla, Nebr. The numbers inclosed in circle give the velocity of ground water in feet per twenty-four hours; the numbers not inclosed indicate th total amount of dissolved solids in the water, in parts per million, at the points where the figures ar placed.

TABLE I.—*Velocity of ground water at Ogalalla, Nebr.*

Date.	No. of station.	Velocity per 24 hours.	Mean velocity per 24 hours.	Direction of flow (east of north).	Depth.	Location.
1905.		*Feet.*	*Feet.*	°	*Feet.*	
ugust 16.....	9	9.2	6.8	112	16	1,600 feet north of north bank of river.
ugust 17.....	10	4.4		100	16	550 feet north of north bank of river.
ugust 1.....	1	13.6	12.8	84	22	In river channel, 200 feet from north bank.
Do.....	2	12.0		90	16	In river channel, 900 feet from north bank.
ugust 6.....	1	2.8	2.55	84	55	In river channel, 200 feet from north bank.
ugust 11.....	1	2.3		84	85	Do.
ugust 15.....	3	3.7	3.55	100	17	100 feet south of south bank of river.
ugust 5.....	4	3.4		54	16	1,400 feet south of south bank of river.
Average.	.....	6.4	.....	88	.....	

The direction of flow for all tests made within the present river hannel was found to be downstream. At this point the river flows ightly north of east. At station 10, located 550 feet north of the orth bank of the river, the direction of flow was S. 80° E., giving a omponent flow toward the river at this point of 0.76 foot per twenty-our hours; at station 9, located 1,600 feet north of the north bank f the river, the direction of flow was S. 68° E., giving a component low toward the river of 3.2 feet per day, and at station 4, located 1,400 eet south of the south bank of the river, the component flow toward he river was at the rate of 2 feet per twenty-four hours. At station 3 the flow was away from the river, probably owing to local leposits of fine sand and silt, since this station was located in a portion of the old river bed. It will be seen from these results that, at least during low stages of the river, the ground waters contribute very largely to the surface flow. A line of levels run across the valley at this point gave the same indications, for it was found that the water plane sloped toward the river channel from both the north and south sides.

During the summer months of 1905 the South Platte was at no time perfectly dry at Ogalalla. There were several small channels within the river bed, some carrying as much as several hundred second-feet of perfectly clear water. These interlocking small channels of the river are cut down 2, 3, and even 4 or 5 feet below the general river bottom, and are fed for the most part by still smaller channels. These smaller rills when traced upstream gradually disappear, and they can be observed to originate in ground water coming to the surface from the underflow. It is claimed by the older residents of this vicinity that these smaller channels did not exist within the river in former years, but that its bed was a flat, sandy stretch from bank to bank. The river has a large number of islands throughout its course through the western part of Nebraska, on which are growing not only grasses and willows, but even small cottonwood trees. In time of flood these islands deflect the current, causing more scour in one part of the river than in another, hence

numerous small channels are found cut down in the river bed when the water lowers. Now that these islands are formed, the smaller living streams will continue to exist within the river itself unless the water plane falls much lower than it is at present.

QUANTITY OF THE UNDERFLOW.

The maximum amount of underflow waters passing through the gravels in the valley of the South Platte at Ogalalla can be readily estimated. The cross section at this point is about the smallest that is found between North Platte and Sterling, but the slope of the water plane is greater than the average throughout the valley. The total cross section of gravels capable of transmitting water is less than 330,000 square feet. The average velocity of the ground water in this material does not exceed 7 feet per twenty-four hours. From this it can be readily concluded that the total amount of ground water passing between the river bluffs at Ogalalla does not exceed 10 second-feet.

While this amount of water is not large, it nevertheless indicates that a considerable quantity of ground water can be safely removed from these underflow gravels, because the supply is renewed at frequent intervals by floods in the river and by the rainfall upon adjacent lands. Any extended use of the ground waters of the valley by means of pumps and wells would tend to lower the water plane, but this in turn would decrease materially the enormous amount of water that now goes to waste in the surface flow of the river and in the evaporation from the sands and soils in the wide river bed and the adjacent low bottom lands. This evaporation undoubtedly reaches 12 inches per month during July and August of an average year.

CHEMICAL ANALYSES OF WATER.

A few simple chemical tests were made of the water drawn from nearly all the test wells sunk in the valley and from existing wells wherever it was thought that such analysis would throw light on the origin or movement of the ground waters.

Portable field apparatus was at hand for the determination of chlorine, alkalinity, and hardness by titration, respectively, with N/10 $AgNO_3$, N/10 HCl, and standard soap solution. The total solids in solution were determined by means of the Whitney electrolytic bridge.

In fig. 1 (p. 10) the numbers not inclosed within circles represent the total solids in solution, expressed in parts per million, at the points corresponding to the position of the numbers in the drawing. The surface water of the river contains about 100 parts per million more dissolved solids than the average water taken from the river gravels on the two sides of the channel. The strongest waters are, however, found in that portion of the river bed at and below the 25-foot level

the slowest movements of the ground waters occur. The total in solution in this part of the bed average 880 parts per million ıe chlorine content is higher than at any other place in the valley, ′erage being 36.9 parts per million. Both total solids and chlo- ncrease slightly with depth within the zone of surface gravels, ; soon as the deposit of river gravels is completely penetrated a n change takes place in the quality of the water. These deeper s are much softer than those in the river sands above them. ferring to the analyses, Table II, and the cross section, fig. 1, it e observed that the waters below the sand contain from 220 to arts per million of total solids. The one exception is a well in ·wn of Ogalalla, which draws water from the deposits just below ırface gravels.

: tests of water from the deposits below the river sands run very ·m with tests of water from wells on the uplands both north ɔuth of the river. These waters are uniformly very much better ;he upper "sheet water" of the valley.

TABLE II.—*Analyses of South Platte Valley waters.*

NEAR STERLING, COLO.

te.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness, as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
6.							
.....	Trace.	172.5	213	240	.....	31	Dr. Johnson's well in sand hills south of Sterling.
.....	3	182.5	208	310	.....	17	Dr. Johnson's well in valley south of Sterling.
.....	42.6	172	386	730	.....	.....	River water, Sterling.

NEAR OGALALLA, NEBR.

5.							
2.....	7.1	126.5	161	220	.....	39	North Platte River water, north of Ogalalla.
.....	10.6	239	223	390	.....	(?)	One-fourth mile south of North Platte River, directly north of Ogalalla.
.....	7.1	194	194	290	62.2	(?)	Well 1½ mile north of South Platte River.
.....	14.9	209	272	360	68.5	24	Well at court-house, Ogalalla.
.....	12.4	185	250	290	.....	25	Nelson's well on Main street, Ogalalla.
18.....	29.1	[a] 387.5	182	400	64	56	Station 9.
.....	28	197.5	281	600	.....	40	Well at Martin Hotel.
.....	14.2	154	267	370	65	75	Union Pacific Railroad well, Ogalalla.
.....	28	145	325	650	75.5	.....	River water, north side.
4.....	38.3	157	403	900	57	55	Station 1.
.....	35.5	175	381	830	66.5	22	Do.
10.....	36.9	140	356	920	58	85	Do.
1.....	27.7	136	324	750	66	16	Station 2.
21.....	12.4	156.5	205	220	59	44	Station 3.
3.....	31.9	152.5	312	640	61	17	Do.
.....	26.3	191	306	640	60	16	Station 4.
14.....	10.6	169	99	250	60	35	Do.
.....	8.9	164	104	200	.....	60	Well on section line one-half mile south of bridge at Ogalalla.
20.....	9.2	165	110	230	.....	200	Southeast corner of NE. ¼ sec. 14, T. 12 N., R. 39 W.
.....	33.4	150	366	720	69.8	.....	Hollingsworth's seepage ditch, at bridge.

[a] *High* alkalinity due to calcareous sediment.

TABLE II.—*Analyses of South Platte Valley waters*—Continued.

IN SAND HILLS NORTH OF PAXTON, NEBR.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
August 31	None.	91.5	58	80	.....	15	In valley of West Birdwood Creek, 7 miles below Big Spring.
Do	....do	91.5	60	90	.....	.....	Big Spring, at head of West Birdwood Creek.
Do	....do	69	40	70	.....	193	2½ miles north of Big Spring.

AT NORTH PLATTE, NEBR.

Date.	Chlorine (parts per million).	Alkalinity, as $CaCO_3$ (parts per million).	Hardness as $CaCO_3$ (parts per million).	Total solids (parts per million).	Temperature (° F.).	Depth (feet).	Location.
1905.							
September 11	3	70.5	6	60	.....	140	Near center of W. ½ sec. 30, T. 15 N., R. 29 W.
Do	3	75.5	8	100	.....	80	Southeast corner of SW. ¼, sec. 12, T. 14 N., R. 30 W.
Do	11.3	139.5	158	300	.....	.....	North Platte River water.
September 7	46.8	192.5	316	600	.....	.....	City waterworks well.
Do	74.6	162.5	282	820	.....	6	Near center of sec. 4, T. 13 N., R. 30 W.
Do	4.6	178	142	210	.....	40	Near center of sec. 22, T. 13 N., R. 30 W.
Do	8.5	176.5	186	280	.....	230	NW ¼ SW ¼ sec. 4, T. 12 N., R. 30 W.

The facts brought out by these analyses show that the ground waters on either side of the valley are not derived from the underflow of the river and that the popular belief that the ground waters of the South Platte seep through the narrow divide into the North Platte is entirely erroneous. The only reason for such belief seems to be the fact that the North Platte, at a distance of only 7 miles, is about 60 feet lower than the bed of the South Platte, and that it carries water for a longer period during the summer months.

Two samples of water from North Platte River were analyzed—one taken at the bridge directly north of Ogalalla August 2, 1905, when there was considerable water flowing in the river, only a few points of the river bottom near the north bank being above water; the other taken at the bridge at North Platte September 11, 1905, when the river had fallen considerably, the water covering not more than one-third of the river bed. The total solids in solution in these two samples were 220 and 300 parts per million, respectively, as compared with 650 parts per million for the water from South Platte River. This difference of composition may in part be due to the fact that the North Platte is fed to some extent by soft water coming from the sand hills north of the river. From the analyses in Table II it will be seen that all samples of water coming from these sand hills are very soft, the total solids in solution ranging from only 60 to 100 parts per million. The softness of this water is due directly to the character of the soil of the catchment area, which is nearly pure quartz sand that immediately absorbs the rainfall and that contains little soluble matter to be taken up.

The sand-hill area in western Nebraska consists of dunes ranging m a few feet to several hundred feet in height, between which are lleys and depressions from a few acres to several sections in extent. is area has no run-off, and of the 17 inches of annual precipitation e greater part enters the sand and raises the water plane much above e level of North Platte River. This water under head seeps out m the sand hills and enters the river, giving rise in places to creeks considerable size, the largest of which are Blue Creek in Deuel unty and Birdwood Creek in Lincoln County.

UNDERFLOW DITCH AT OGALALLA.

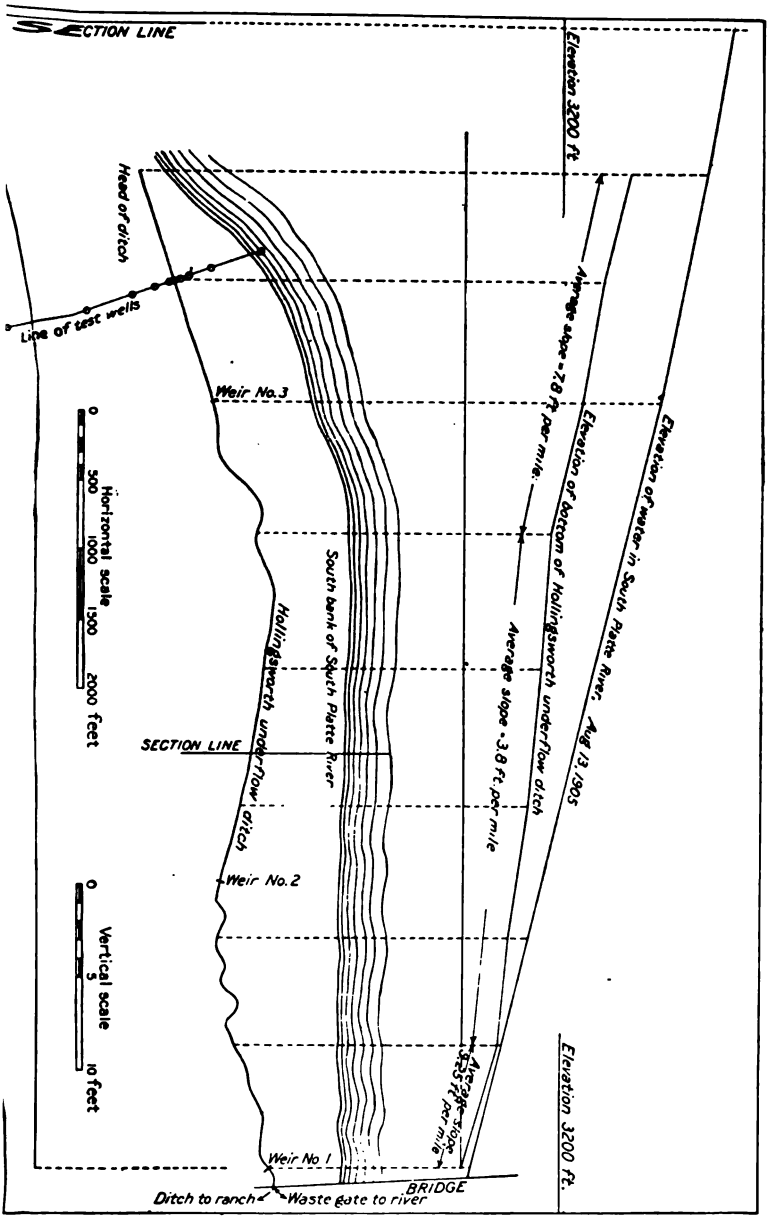
One of the interesting developments in the South Platte Valley is underflow ditch on the south side of the river at Ogalalla, owned Dr. A. Hollingsworth. This canal was constructed in 1895 and s been in use ever since. It extends along the south bank of the er bed, is about 12 feet wide at the bottom and about 6,500 feet ıg, and reaches a total depth in its upper portion of 5 feet below e bed of the river. A map of this ditch is given in the lower part of .2 (p. 17); in the upper part are represented in profile the bottom of e ditch and the river bed. The profile of the river bottom was ade from elevations of the surface of the water in the river, deter- ined August 13, 1905. The river at this time was nearly dry, the ater flowing in only a few small channels, as described above. The ıe of levels run on this day, from the section line shown at the left the figure to the section line 2 miles below, gave a drop of 16.7 feet the river water, or a slope at this point of 8.35 feet to the mile. he distance from the head of the ditch to the line of test wells, as ıown in the figure, is 800 feet; below this, the distance between ›ints shown by consecutive dotted lines is 1,000 feet measured along ıe line of the ditch. For the first 1,000 feet above (west of) weir o. 1, the bottom of the ditch is about on a level with the bottom of ıe river. For the next 4,000 feet (west) its grade drops to 3.8 feet ›r mile; and from thence to its head it again has approximately the ade of the river. From its head to within about 1,000 feet of the idge the ditch is cut in sand, and thence down to the point where it is ırried up above the water plane it passes through a kind of clay am, through which there must be considerable seepage before the ater reaches the point of application. On account of an unusually nple rainfall during the summer of 1905 the water recovered by the tch was not used for irrigation, but was permitted to run back into ıe river, so that no opportunity was offered for measuring the loss om the lower part of its course.

The flow of the canal is obstructed by rank vegetation growing ithin it. A large amount of seepage was observed to enter from the uth margin of the canal.

TABLE III.—*Flow of water in Hollingsworth ditch.*

Date	Time.	Flow over weir No. 1.	Flow over weir No. 2.	Flow over weir No. 3.	Elevation of water in river (datum 3,208.51 feet above mean sea level.)	Remarks.
1905.		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet.*	
August 6	4 p. m.	3.77			1.20	Weir No. 1 put in ditch.
August 7	5 p. m.	2.83	2.28			Weirs Nos. 2 and 3 put in dit
August 9	11 a. m.	3.06	2.86	2.22	1.05	
August 10	12 m.	3.03	2.82	2.13	84	
August 11	12 m.	2.67				
August 12	12 m.	3.39			.89	Heavy rain night of August
August 13	8 a. m.	3.36	3.16	2.11		August 12 very cloudy, wi showers.
August 14	12 m.	3.12			.77	
August 15	8 a. m.	3.36	3.14	2.16	.70	
Do	9.30 a. m.	3.34			.70	
Do	12 m.	2.97			.67	
Do	4 p. m.	3.06				
Do	6 p. m.	3.16			.64	
August 16	8.30 a. m.	3.12			.60	
Do	10 a. m.	3.06			.60	
Do	12 m.	2.77			.58	
Do	2.30 p. m.	2.68			.55	
Do	7 p. m.	3.02			.53	
August 17	8 a. m.	3.20	3.14	2.12	.53	
Do	12 m.	2.96			.50	
Do	2.30 p. m.	2.67			.50	
Do	4 p. m.	2.72			.50	
Do	5.30 p. m.	2.94			.50	
August 18	8.30 a. m.	3.06	2.94	2.03	.50	
Do	10.45 a. m.	2.96			.48	
Do	4.45 p. m.	2.86			.47	
August 19	8 a. m.	2.96				
Do	3.30 p. m.	2.67				Weir No. 2 removed from ditch 19, 3.30 p. m., lowering the back of it 1.33 feet.
August 20	8.30 a. m.	3.59				
Do	11 a. m.	3.40				
Do	3 p. m.	3.27				
Do	8 p. m.	3.55				
August 21	8 a. m.	3.49				
Do	9.30 a. m.	3.38				
Do	12 m.	3.21				
Do	3.30 p. m.	3.21				
Do	4.15 p. m.	3.22				
Do	7 p. m.	3.31				

The discharge from this ditch, measured with a current I August 5, 1905, was found to be 3.78 second-feet. Later three were placed at different points in the ditch and continuous re were kept for several days. These measurements are given in' III and are represented graphically in fig. 3 (p. 18). Weir No. 1 w in at the bridge, near the mouth of the ditch (see fig. 2), August 6, The discharge from the ditch measured over the weir August found to be 3.77 second-feet, checking the measurement mad previous day with the current meter. Weirs Nos. 2 and 3 were p place, at locations shown on fig. 2, August 7, 1905, after whic discharge over weir No. 1 fell from 3.77 to 2.83 second-feet at a sponding hour of the day. This diminution of 0.9 second-foo due to the backing up of the water behind the two additional thus decreasing the effective head which forces the water int



2.—Map of Hollingsworth underflow ditch, Ogalalla, Nebr. The lower portion of the diagram ıws the location of the ditch with reference to the south bank of the river; the upper portion shows elevation of the bottom of the ditch and of the running water in the river August 13, 1905. The ıtion of weirs placed in the canal for the purpose of measuring the flow is shown on the map; also location of a line of test wells put down to determine the elevation of the water plane near the h.

ditch. Weir No. 2 was removed August 19, 1905, and the disc over weir No. 1 rose from 2.67 second-feet at 3.30 p. m. to 3.27 se feet at 3 p. m. August 20—1 the former amount, notwiths ing the facts that weir No. still in place and that the riv gone down 0.8 foot. The re of weir No. 2 lowered the s of the water immediately b it 1.33 feet.

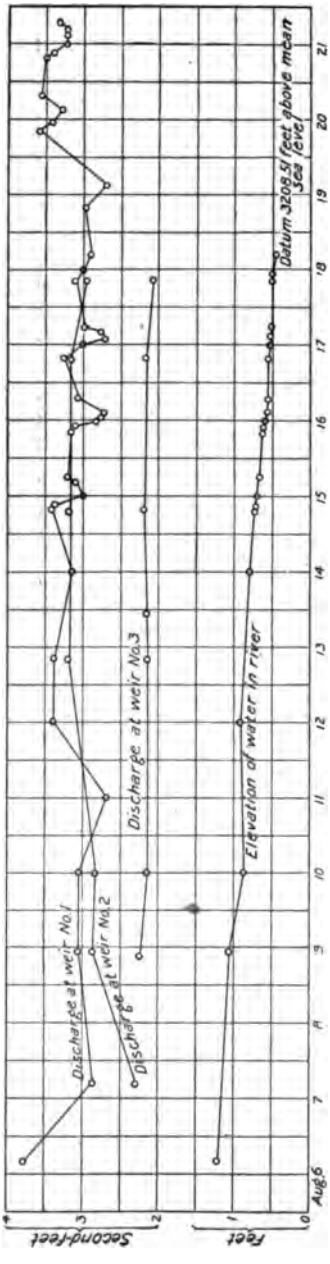


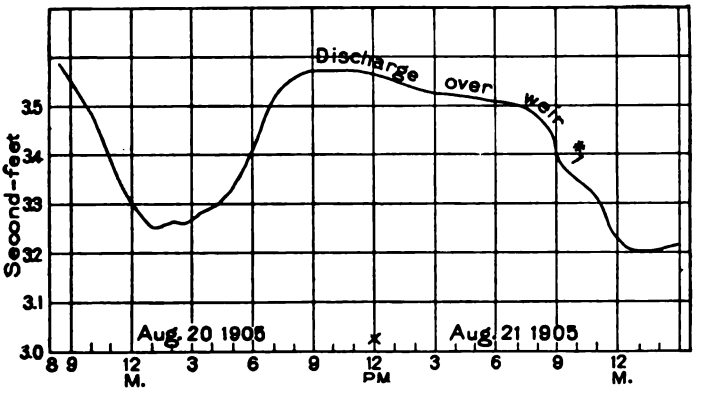
FIG. 3.—Diagram showing discharge over weirs Nos. 1, 2, and 3 in the Hollingsworth underflow ditch and the elevation of the water in the river between August 6 and 21, 1905. Small circles indicate the observed values. These are connected by straight lines, although more frequent observations would have shown a diurnal fluctuation in the discharge and the straight lines would have been replaced by curves.

It was found that the disc from the ditch changed ap ably with a slight change c vation of the river water. example, from 8 a. m. Aug to 8.30 a. m. August 18 the fell 0.2 foot, the discharge weir No. 1 fell 0.3 second-foot weir No. 2, 0.2 second-foot over weir No. 3, 0.13 second

From these data the s capacity of the gravels in th tom of the ditch was found between 0.01 and 0.02 gallo minute per square foot of lating surface under a head foot, a value much less tha expected. This result may b tially explained by the fac no work had been done o ditch since the previous irri season. In consequence a growth of vegetation spra not only along the banks b out into the water and at extended from bank to There was also a tightly att covering of moss or algæ ov entire bottom of the ditch.

The above results, while si ing little concerning the bearing qualities of the g show that a very little ext penditure of work on the ditch would greatly increase its yield. tor Hollingsworth says that loosening the moss from the bott

ditch by dragging a log through it with a team of horses increases lischarge at least 50 per cent.



4.—Diagram showing discharge of Hollingsworth underflow ditch from 8 a. m. August 20 to 3 p. m. ıgust 21, 1905, made from autographic record of a self-recording water register placed above the ıs. The diagram shows the decreased flow from the ditch during the midday hours.

t was further determined, from the measurements obtained, that flow from the ditch fell off greatly during the middle of the day remained nearly constant from the late afternoon until the ming hours of the next day. flow at midday was about per cent less than the flow ing the night. The cause his fluctuation was investıted, and the conclusion was ched that the decrease was primarily due to evaporaı from the water surface l the gravels near the ditch, mainly to the enormous of water by vegetation wing in and along its banks. automatic gage was put in ditch a few feet above r No. 1, from which a conıous record of the discharge r this weir could be comed. The results of these ographic records are given igs. 4, 5, and 6, together ı the change in temperaof the air and of the water in the ditch.

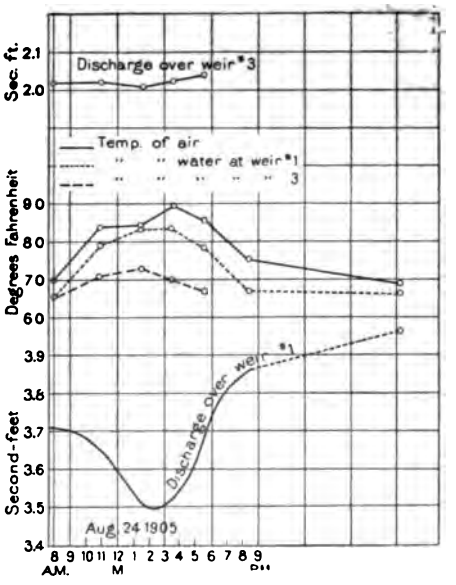


FIG. 5.—Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 24, 1905. This diagram shows the decreased flow in the middle of the day.

n estimate of the evaporation from the surface of the water in the

canal can readily be made. The length of the canal is 6,500 feet and its average width is 12 feet, making the area of surface 78,000 square feet. Evaporation experiments were conducted by the writer during the summer of 1905 at Deerfield, Kans., 200 miles south of Ogalalla, the conditions being essentially the same at the two points. The results are given in Table IV:

TABLE IV.—*Evaporation in inches of water at Deerfield, Kans., from August 6 to September 3, 1905.*

	For 28 days.	Average for 1 day.
Open water	10.90	0.39
Cultivated soil, 1 foot to water	4.88	.17
Uncultivated soil, 1 foot to water	5.83	.21
Uncultivated soil, 2 feet to water	2.23	.08
Uncultivated soil, 3 feet to water	.80	.028

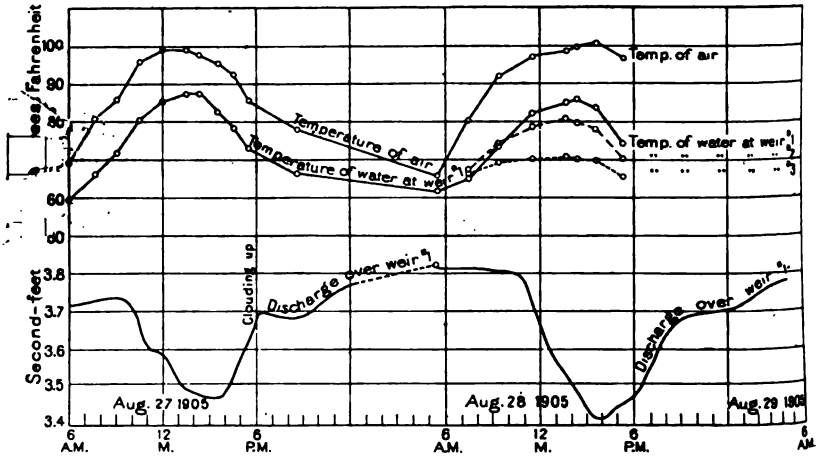


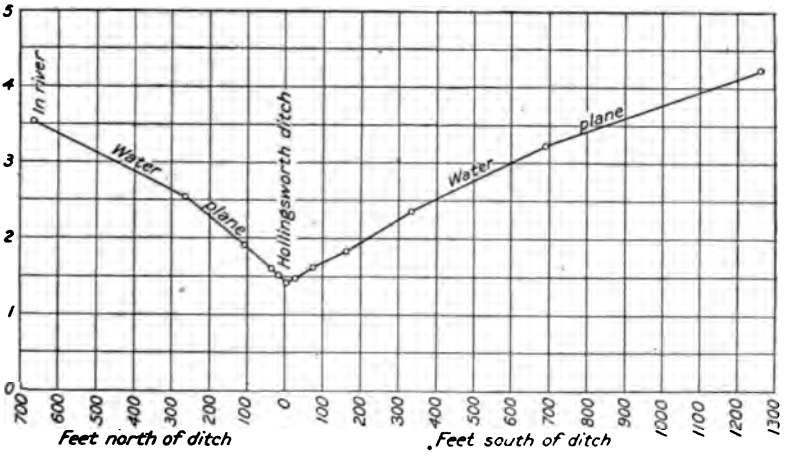
FIG. 6.—Diagram showing discharge of Hollingsworth underflow ditch and the temperature of the water and the air August 27 and 28, 1905. The discharge over the weir was measured by an automatic recording water register. The curve shows the sharp drop in the discharge in the middle of the day and the nearly uniform discharge during the night.

The result from open water is equivalent to an average evaporation of 0.0325 foot per day, or a total average evaporation of 2,535 cubic feet of water per day from the surface of the water in the underflow canal. If it be assumed that this loss took place during eight hours of midday, it should have shown itself by a falling off in the discharge from the underflow canal of 0.084 second-foot. The actual observed loss amounted to 0.3 second-foot. Thus direct evaporation can account for barely 23 per cent of the observed loss. The evaporation from the wet banks of the canal may possibly have increased the loss to the equivalent of 0.1 second-foot, still leaving two-thirds of the amount to be accounted for by the use of water by vegetation and *other losses.*

ı line of test wells (fig. 2, p. 17) at right angles to the ditch, 800 feet n its head, was put down for the purpose of determining the ression of the water plane in the neighborhood of the ditch. The file of the water plane found in these wells is given in fig. 7.

'he point of especial interest in connection with the Hollingsworth lerflow ditch is the fact that it is probably the only construction ts kind near any of the streams of the western plains which can be sidered a success. As previously stated, nearly all such ditches in er localities in the Western States have proved to be failures.

'he conditions at this particular point are especially favorable. › fact that the size of the development is small has also contributed its success. The slope of South Platte River at Ogalalla is ısually large, amounting to about 1.6 feet per thousand. The



7.—Profile of water plane at line of test wells near the head of the Hollingsworth underflow ditch The position of this cross section is given on the map (fig. 2, p. 17).

ıimum slope of the underflow ditch is 0.7 foot per thousand. The t of construction was about $3,000, including at the standard e the time of the owner and of his teams used in the construction. ɜ ditch requires cleaning at frequent intervals—at least once every › years—in order to remove the vegetation and the sand which ds to gradually ooze up from the bottom and fill the canal. From nancial standpoint the underflow ditch is about on a par with a nping plant of the same capacity in the same location. The cost ›peration is not very different from the cost of operating a Corliss densing engine and centrifugal pump connected to a battery of ven wells, and there is little difference in the first cost. A pump- plant in one respect would be very much more satisfactory, smuch as there is constant danger that the underflow ditch will ome a total loss at any time, owing to an unusually heavy flood he river breaking over the banks and filling it or washing it out.

DISADVANTAGES OF UNDERFLOW CANALS.

As stated above (p. 18), the percolation into the Hollingsworth infiltration canal, for each square foot of percolating surface, amounted to only 0.01 to 0.02 gallon per minute, under 1 foot head. Tubular wells constructed in the same gravels show a specific capacity of 0.25 to 0.5 gallon of water per minute for each square foot of strainer surface, under 1 foot head. The low specific capacity of the underflow canal is due not only to the obstruction of the sand, through which the water must pass by vegetation and slime, but mainly to the fact that stratified gravels do not readily transmit water across or perpendicular to the direction of the bedding. When tubular wells are put down vertically in bedded gravel, the coarser streaks of gravel drain the water into the well strainer and the capacity of the well is determined largely by the coarsest layers of the gravels encountered. In the underflow ditch the water must reach the surface by passing across the various beds of gravel, and the finest layer of sand controls the rate at which the water can enter the canal. On this account wells that penetrate gravels perpendicular to the bedding are much preferred to horizontal wells or to underflow canals that must follow the direction of the bedding. For the same reasons a deep tubular well of small diameter will furnish much more water than a shallow dug well of large diameter.

An underflow ditch is also undesirable on account of the inelasticity in the amount of water which it will yield. The distance to which the water level is lowered by the underflow canal is fixed at the time of construction, and the daily yield can not be increased beyond a certain maximum; in fact, at the very time when the most water is needed—say in the month of August—the yield of the underflow canal will be near its minimum value. When water is recovered by pumping from tubular wells, the vacuum of the pumps can be increased for short intervals of time to correspond to the increased demand for water.

It should also be noted that very few infiltration or underflow canals are in actual use for irrigation purposes. There are many pumping plants in use for irrigation which have turned out to be both practicable and financially profitable; but the attempts to secure ground water by gravity have usually proved disappointing and there are numerous abandoned underflow canals in many parts of the West. An underflow ditch was constructed in 1890 in the valley of Arkansas River near Hartland, Kans., about 12 miles west of Deerfield, for the purpose of furnishing water to the Great Eastern canal. In the summer following its construction the flow from the canal amounted to a little over 5,000 gallons per minute. Water from the river overflowed the ditch during a flood and partially filled it with sediment; a

he same time the gravels in the bottom of the canal showed a tendency o work themselves upward by slow movement to the level of the ground water, cutting down materially the head under which the water entered the canal. The ditch proved a complete failure and a great disappointment to the people. A large underflow ditch constructed at great expense near Dodge, Kans., had practically the same history as the one at Hartland. The Denver Union Water Company put an underflow gallery in Cherry Creek, at a cost of $200,000, and succeeded in developing only 5 second-feet of water. An expensive infiltration canal near Sacaton, Ariz., on the Gila Indian Reservation, was wholly unsuccessful. A gravity infiltration canal constructed on Cimarron River near Englewood, Kans., consisted of 900 feet of stave pipe and 2,000 feet of open canal. A flood in the river filled the canal with sand and mud soon after its completion, and it was a total failure.

INVESTIGATIONS AT NORTH PLATTE, NEBR.

SLOPE OF THE WATER PLANE.

Several miles of levels were run at North Platte to determine the slope of the water plane toward the bottom lands, both south and north of South Platte and North Platte rivers, and to determine whether or not the position of the water plane had changed since 1890, when W. W. Follett plotted the elevation of water in a north-south line of wells crossing the Platte Valley at this point. In the lower part of fig. 8 the wells used by Mr. Follett are represented by dots and those used by the field party in 1905 are represented by small circles. In the upper part of the figure is represented the elevation of the water in these wells.

South of the river the water plane was found at about the same elevation as determined by the line of levels run by Mr. Follett; but on the north side, within the sand-hill district, the water plane was about 8 feet lower than it was in 1890. The lowering of the ground water n the north side of the river, where its source is the rainfall upon the and area, may be due partly to the fact that within this period there as been an unusually large number of years when the precipitation was uch less than the normal. The amount of ground water removed om the wells is insignificant. The sand-hill country is used for cattle azing, and while the number of cattle on the range is probably not great at present as formerly, during dry years it is always greatly ergrazed. This may be the principal cause of the lower water level. Stearns's well, shown at the north end of the line of levels, was illed during the spring of 1905.

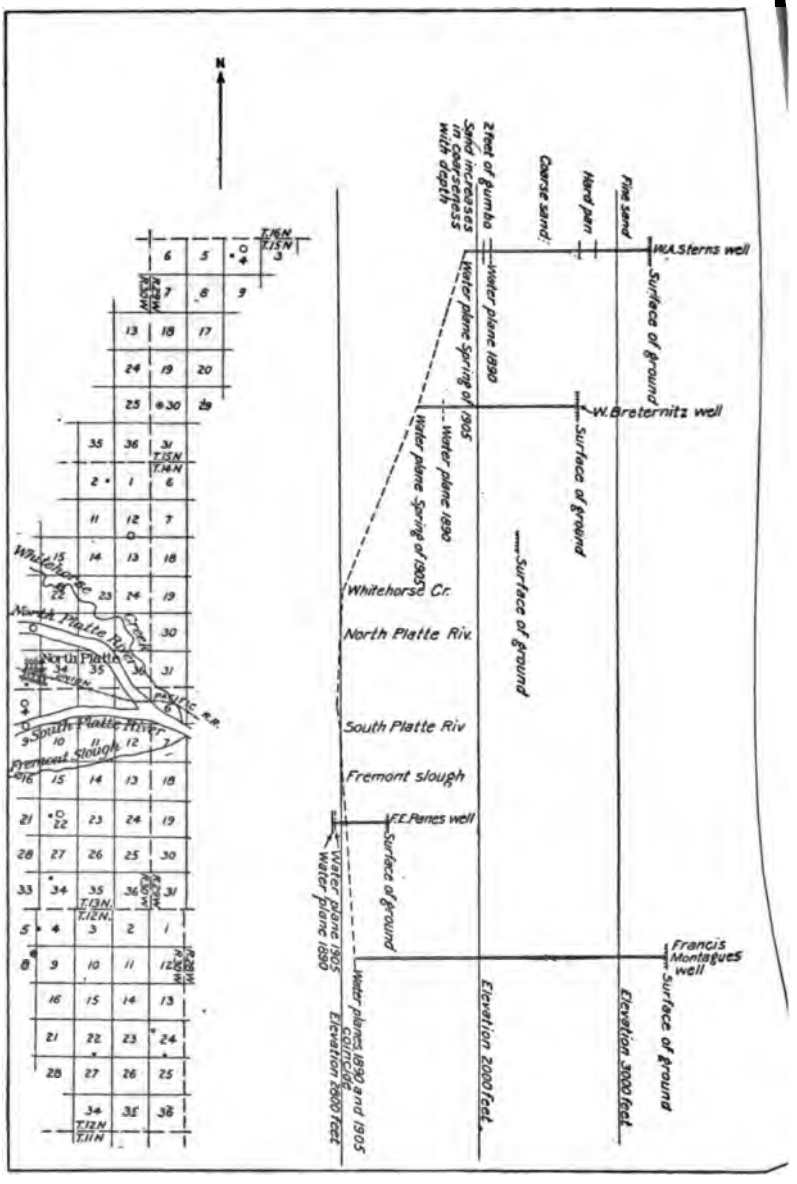


FIG. 8.—Diagram showing change in elevation of the ground water at North Platte, Nebr., bet 1890 and 1905. The location of the wells used by W. W. Follett in 1890 to determine the elevati the water plane is shown on the map by black dots. The circles show the location of the wells to determine the elevation of the water plane in 1905.

ORTH PLATTE CITY WATERWORKS PUMPING PLANT.

plant of the North Platte waterworks two 10½-inch duplex tion steam pumps are connected to a gang of 28 6-inch deliver water under direct pressure. In fig. 9 the wells are from 1 to 28. The second number for each well represents in feet. Wells 1 to 22 have screens made of perforated it 4 feet long; wells 23 to 28 have 12-foot Cook strainers; all led with a 4-inch suction pipe.

ber 15 and 16, 1905, observations were made at this plant to , if possible, the approximate specific capacity of the gravels rt of the valley. On these days the south pump (H) only ng, and wells 6, 13, 14, 17, 18, 19, 20, 21, and 22 were gated ig only 19 wells from which water was pumped. Well 14 and offered an opportunity for measuring the fluctuation of level at this point due to different rates of pumping at differ- of the day. These measurements are given in column 4 of

Observed and computed data from test of city waterworks pumping station at North Platte, Nebr., September 15–16, 1905.

1.	2.	3.	4.	5.	6.	7.	8.
	Observed data.					Computed data.	
ime.	Time for 20 cycles of pump.	Vacuum gage.	Depth of water below top of abandoned well.	Length of stroke of pump.		Depth of water below normal.	
				North cylinder.	South cylinder.	In abandoned well.	In pumped wells.
	Seconds.	*Inches mercury.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
.....	39.2	11	5.38	.....	.....	.....	.....
.....	37.2	11.5	5.66	.....	.....	.....	.....
.....	35.8	11.4	5.84	0.86	0.93	1.54	3.15
.....	32.8	12.4	6.03	.90	.96	1.73	3.55
.....	30.7	13	6.25	.....	.....	.....	.....
.....	33.2	12.6	6.41	.88	.96	2.11	4.35
.....	30.7	12.9	6.54	.89	.98	2.24	4.60
.....	31	12.9	6.64	.....	.....	.....	.....
.....	29.8	13.1	6.73	.90	.97	2.43	4.97
.....	45	10.7	6.30	.78	.88	.....	.....
.....	106	9	5.10	.58	.84	.....	.....
.....	100	9	4.76	.58	.81	.46	.90
.....	91	9	4.66	.58	.82	.36	.70
.....	93	9	4.63	.60	.82	.....	.....
.....	67.3	9	4.62	.64	.85	.....	.....
.....	61.4	9.5	4.86	.....	.....	.....	.....
.....	43	10	5.06	.82	.88	.76	1.55
.....	43	10.4	5.15	.....	.....	.....	.....

ific capacity of gravels = 0.31 gallon per minute. Assumed slip of pump = 10 per cent.

idings of a vacuum gage inserted in the suction pipe just enters the pump are given in column 3 of Table V. These are very rough, since the gage fluctuated badly with the the pump, and the true vacuum could only be estimated. the large number of gage readings taken over a considerable

range, together with the readings taken on the open well, the puted values in columns 7 and 8 of the table can not be far from rect. Fom the data in columns 5, 6, and 8 the specific capacity sands was found to be about 0.3 gallon per minute, the slip pump being assumed to be 10 per cent. The specific capacit well is a numerical statement of the readiness with which th furnishes water. It ex the amount of water fu per square foot of strai face, if the water level ered but 1 foot. This is large in the case of well and small in the a poor well.[a] In the case each square foot of er surface in the wells fu an average of 0.3 ga water per minute unde head. This is a large and indicates an e grade of water-bearing rial. This specific c can probably be relied wells in the South Pla ley. The waterworks a Platte are in constant tion, so that the spec pacity measured abov value after long-co pumping has taken pl hence a minimum amo

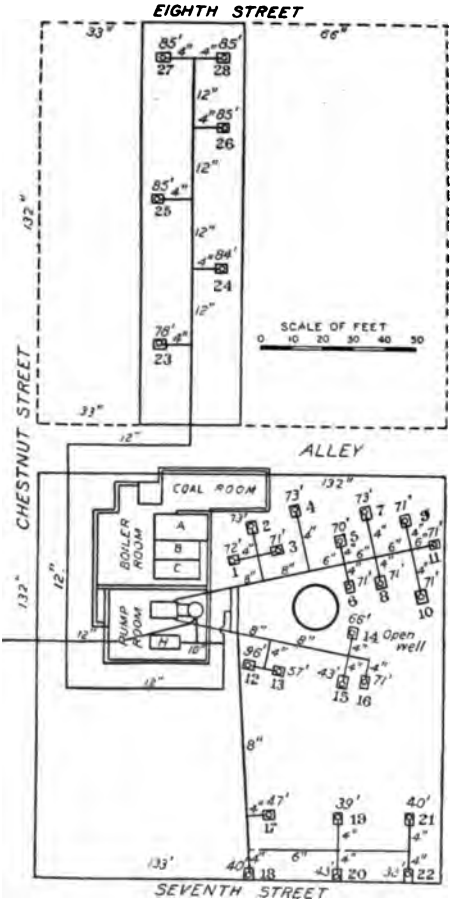


FIG. 9.—Map of the city waterworks pumping plant at North Platte, Nebr. The position of the wells and suction pipe is indicated in the diagram. The second number for each well indicates its depth where known.

SPRINGS AND ARTESIAN OF BIRDWOOD CRE

Birdwood Creek, a pe stream with a low-sta of about 150 second-f with a drainage area entirely within the sa enters North Platte River about 16 miles west of North Nebr. The head of the stream is nearly 20 miles to the It has only two branches; one is a very small stream enter creek near its head; the other, West Birdwood Creek, flow easterly direction a distance of nearly 14 miles and joins th

[a] See Water-Sup. and Irr. Paper No. 140, U. S. Geol. Survey, 1905, p. 66.

stream 11 miles above its mouth. The flow of West Birdwood Creek at the junction is nearly as great as that of the main stream itself, and perhaps for this reason the stream is locally spoken of as having an east and a west fork. Above the forks the two branches of Birdwood Creek are cut down from 100 to 200 feet into the sand-hill deposit, with no valley bottom, the steep banks in most places extending down to the water's edge. The stream flows in this deep cut some distance below the general level of the water plane. This conclusion is justified by the fact that for nearly its entire course there is a strong seepage from both banks extending many feet above the bed of the creek.

Birdwood Creek is fed entirely by seeps along its banks and by numerous springs, some of which, at the head of the west branch and about 7 miles below the head of the east branch, are of enormous size. The description of these springs by the residents of the valley indicated that there was some probability of the ground waters being under artesian head. This matter was accordingly investigated by sinking a 2-inch well in one of the large springs at the head of the west branch, near the center of sec. 4, T. 16 N., R. 35 W. An artesian head, increasing with depth, developed during the sinking of this well; at a depth of 40 feet the water rose over 20 feet above the bed of the creek.

The log and distance to water for two wells located near the head of West Birdwood Creek were furnished by the owners. One well, 3 miles directly south of the big springs, on the ranch of Mr. F. L. Jones, in the SW. ¼ sec. 21, T. 16 N., R. 35 W., is in coarse gravel which begins at a depth of 275 feet. Above the gravel are several thin layers of hardpan, and above the hardpan is a very fine sand extending continuously to the surface. In this well the water plane is at a depth of 60 feet. The second well is on the ranch of Mr. C. W. Alexander, 2½ miles north and 1 mile west of the big spring, near the northwest corner of the SE. ¼ SE. ¼ sec. 21, T. 17 N., R. 35 W. This well was put down through 169 feet of very fine sand, 12 feet of hardpan, and for 12 feet into coarse gravel. From these data, and from elevations taken from a contour map of this region, fig. 10 was drawn. From this diagram it will be seen that the maximum artesian head which can be developed at this point should be about 25 feet—a pressure nearly equal to that found by sinking the test well in the spring. It may also be observed that the coarse gravels should be encountered at a depth not exceeding 160 feet.

The waters of Birdwood Creek are taken out just above its mouth on North Platte River and diverted into an irrigation canal, which serves the bottom lands of the river. The discovery of the artesian head of the water in Birdwood Creek makes it possible to augment greatly the low-stage flow of this stream and the supply of water for the existing irrigation canal, or a new one. It will be an inexpensive

matter to sink a number of 12-inch wells to the artesian water suitable localities along the stream, and to provide these wells w

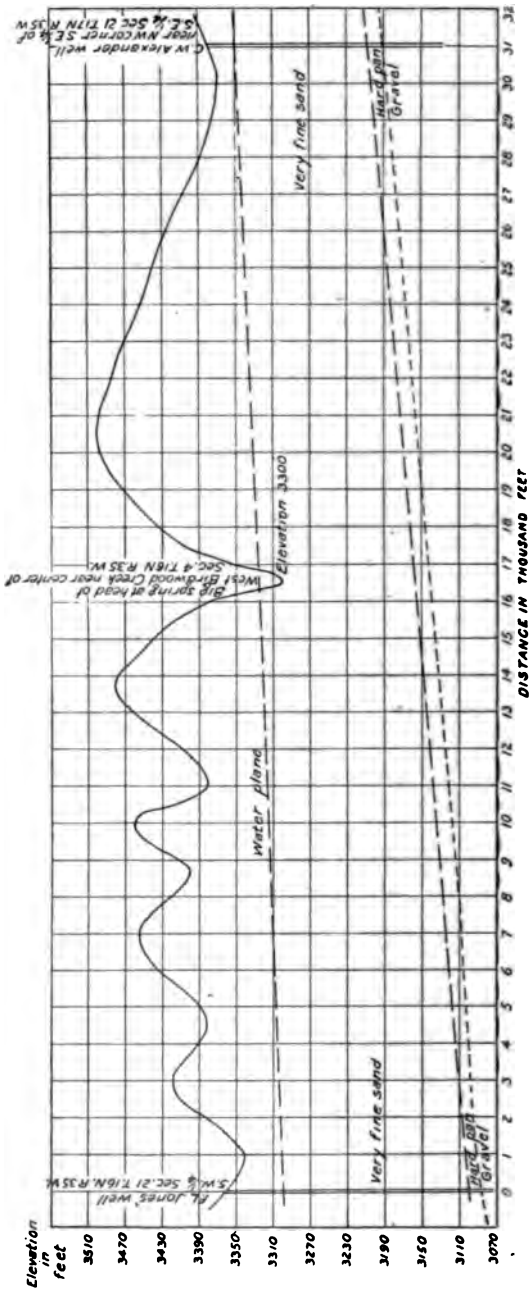


FIG. 10.—Diagram showing the position of the water plane and the coarse water-bearing gravel near the head of West Birdwood Creek. The diagram shows that wells sunk in the valley of Birdwood Creek to the depth of the coarse gravels would have an artesian head of about 28 feet.

gates or valves which can be opened during low stages of flow is very probable that the present minimum flow of Birdwood C ld be doubled by such means.

JGGESTIONS FOR THE CONSTRUCTION OF SMALL PUMPING PLANTS.

The investigations in the South Platte Valley indicate that there an ample supply of ground water for a large number of small pump-g plants located in almost any part of the bottom lands. It is pos-ble to count on an average depth of 40 to 60 feet of good water-aring gravels. These deposits contain a sufficient amount of coarse aterial to render it unnecessary to use fine-meshed strainers in the ells. In a large portion of the bottom lands the distance to water between 5 and 15 feet, making it easy to pump the water and place on the surface of the ground economically. The cost of pumping ill be controlled, primarily, by the cost of fuel and the distance it necessary to lift the water. Whether a pumping plant will be a rofitable investment depends, of course, very largely on the crops at can be grown and marketed at a fair price.

KIND OF WELLS ADAPTED TO THE SOUTH PLATTE GRAVELS.

The most economical well to construct for the purpose of procuring round water in the large quantities needed for irrigation purposes one from 12 to 15 inches in diameter and extending into the water-earing gravels a distance of 30 to 60 feet, depending on the thickness the gravels at the place where the well is drilled. Strainers for ese wells can be made of slotted galvanized iron. The perforated etal should be placed opposite all the coarse gravels, below a depth 10 feet below the surface of the water. These strainers can be ade by any mechanic by punching heavy galvanized iron with slots out one-eighth by 1 inch in size and then riveting the sheets into linders of the proper diameter. The cylinders should be rolled so at the burr made by punching the slots will come on the outside of e finished casing and so that the slots will be arranged vertically the finished well. A much better strainer can be made if the metal purchased in sheets already perforated. For this purpose steel eets 48 by 60 inches, perforated with hit and miss slots, three-teenths by 1 inch, and galvanized after the perforations are made, ll be found to be ideal strainers. When rolled into cylinders these eets form a casing about 15 inches in diameter. In constructing e well the perforated sections should be put in place, one above nother, to a point about 10 feet below the water level, from this pth upward the casing should not be perforated.

AMOUNT OF WATER THAT CAN BE OBTAINED.

Wells constructed as described in the preceding section can be lied on to furnish at least one-fourth gallon of water per minute for ch square foot of strainer surface in the well when the water in the ell is lowered 1 foot by pumping. If the water in the well is lowered

matter to sink a number of 12-inch wells to the artesian wate
suitable localities along the stream, and to provide these wells

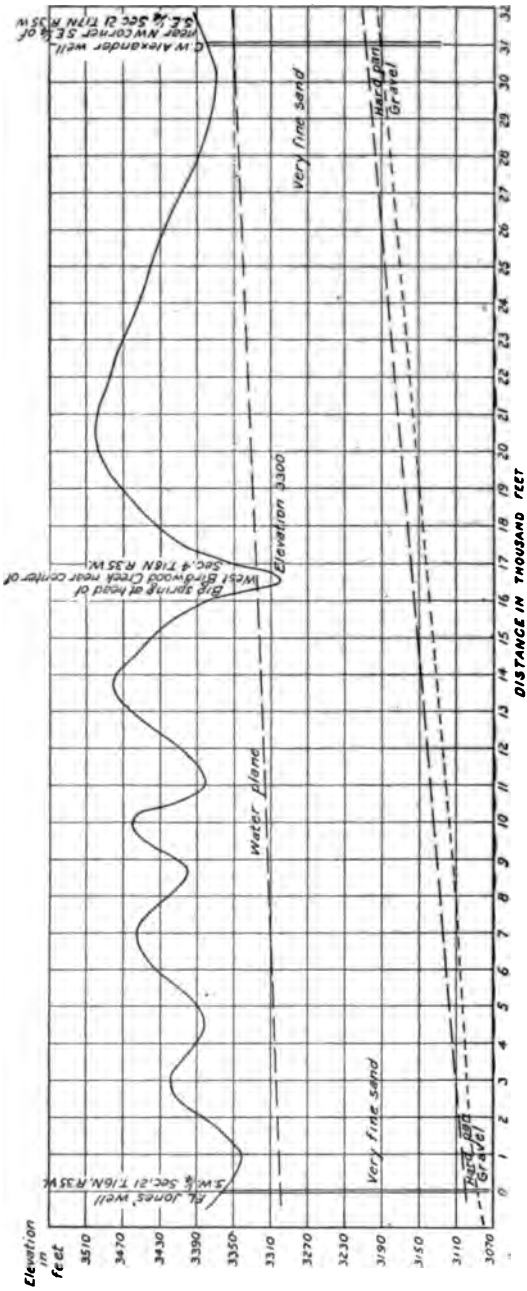


FIG. 10.—Diagram showing the position of the water plane and the coarse water-bearing gravel near the head of West Birdwood Creek. The diagram shows that wells sunk in the valley of Birdwood Creek to the depth of the coarse gravels would have an artesian head of about 25 feet.

gates or valves which can be opened during low stages of flow.
is very probable that the present minimum flow of Birdwood C
could be doubled means.

GGESTIONS FOR THE CONSTRUCTION OF SMALL PUMPING PLANTS.

'he investigations in the South Platte Valley indicate that there n ample supply of ground water for a large number of small pump- plants located in almost any part of the bottom lands. It is pos- e to count on an average depth of 40 to 60 feet of good water- ring gravels. These deposits contain a sufficient amount of coarse terial to render it unnecessary to use fine-meshed strainers in the ls. In a large portion of the bottom lands the distance to water etween 5 and 15 feet, making it easy to pump the water and place n the surface of the ground economically. The cost of pumping l be controlled, primarily, by the cost of fuel and the distance it ecessary to lift the water. Whether a pumping plant will be a fitable investment depends, of course, very largely on the crops t can be grown and marketed at a fair price.

KIND OF WELLS ADAPTED TO THE SOUTH PLATTE GRAVELS.

'he most economical well to construct for the purpose of procuring und water in the large quantities needed for irrigation purposes ne from 12 to 15 inches in diameter and extending into the water- ring gravels a distance of 30 to 60 feet, depending on the thickness he gravels at the place where the well is drilled. Strainers for se wells can be made of slotted galvanized iron. The perforated al should be placed opposite all the coarse gravels, below a depth 10 feet below the surface of the water. These strainers can be le by any mechanic by punching heavy galvanized iron with slots ut one-eighth by 1 inch in size and then riveting the sheets into nders of the proper diameter. The cylinders should be rolled so t the burr made by punching the slots will come on the outside of finished casing and so that the slots will be arranged vertically he finished well. A much better strainer can be made if the metal urchased in sheets already perforated. For this purpose steel ets 48 by 60 inches, perforated with hit and miss slots, three- eenths by 1 inch, and galvanized after the perforations are made, l be found to be ideal strainers. When rolled into cylinders these ets form a casing about 15 inches in diameter. In constructing well the perforated sections should be put in place, one above ther, to a point about 10 feet below the water level, from this th upward the casing should not be perforated.

AMOUNT OF WATER THAT CAN BE OBTAINED.

Vells constructed as described in the preceding section can be ed on to furnish at least one-fourth gallon of water per minute for h square foot of strainer surface in the well when the water in the l is lowered 1 *foot by pumping*. If the water in the well is lowered

10 feet by pumping, the amount of water recovered should amount to at least ten times as much, or 2½ gallons per minute per square foot of strainer. If a 15-inch well is drilled in good water-bearing gravel to a depth of 40 feet, the lower 30 feet of which is strainer surface, and if the pump lowers the water in the well 10 feet, the amount of water supplied by the well should amount to at least 300 gallons per minute. It is believed that this estimate is conservative. A careful test of the waterworks at North Platte, Nebr., showed that the strainers in the wells were furnishing 0.3 gallon of water per minute per square foot of strainer surface, when the water in the wells was lowered 1 foot by pumping.

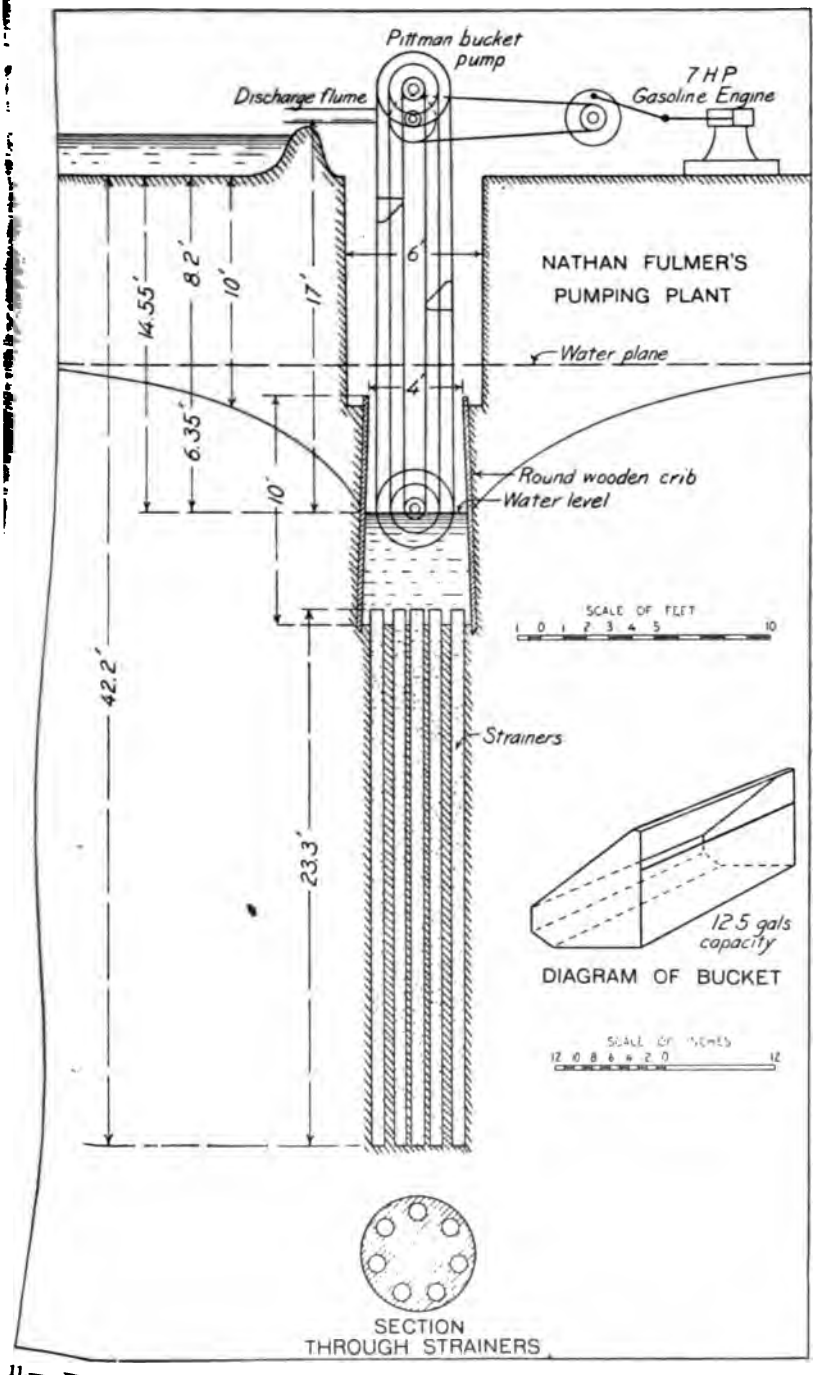
For small pumping plants a single well of the depth indicated above would probably be sufficient for the supply; but if the good water-bearing gravels do not extend to the requisite depth, it would be necessary, of course, to increase the number of wells and connect several of them by suitable means to the pump.

DISTANCE BETWEEN WELLS.

If it is necessary to construct several wells in order to obtain the amount of water required for an irrigation plant, it becomes important to consider the best and most economical arrangement of the wells. Two different methods will be found available for this purpose. If the amount of water required is not greatly in excess of that which can be supplied by a single tubular well, it is often found practicable to construct a large dug well 6 to 10 feet in diameter to a depth of 5 to 10 feet below the water level, inserting in the bottom of the dug well several feeders of perforated galvanized iron, as described above. This method has the advantage of permitting the pump that is to recover the water to be submerged in the water of the well. A well of this sort is shown in fig. 11.

In order to sink a dug well the proper distance below the water level, it is necessary to construct a wooden, brick, or concrete case that will sink as the material is removed from its interior. The case of the well shown in fig. 11 is made of wood, and is larger at the lower than at the upper end to facilitate sinking.

Another method of recovering a large quantity of water is to sink a battery of wells and connect them by suction pipe to the pump. This method is adapted to secure a greater supply than the large dug well. Various arrangements of the wells can be made. Three, four or more wells can be arranged in a straight line 20 or 30 feet apart and connected by suction pipe to a pump placed near the center of the row of wells. In fig. 12 is shown an arrangement suitable for a battery of eight to twelve wells. These wells are arranged in pairs placed close together, each pair of wells being 40 to 60 feet from the next pair on the same suction line. The object of placing the wells



11.—Diagram of a pumping plant in the rkansas Valley in which the water is recovered from a g well having a wooden crib in the bottom of which are placed seven galvanized-iron strainers. feed ers. A chain-and-bucket pump is used on this well. Better results would undoubtedly be ain ed by using a vertical-shaft centrifugal pump submerged in the open well.

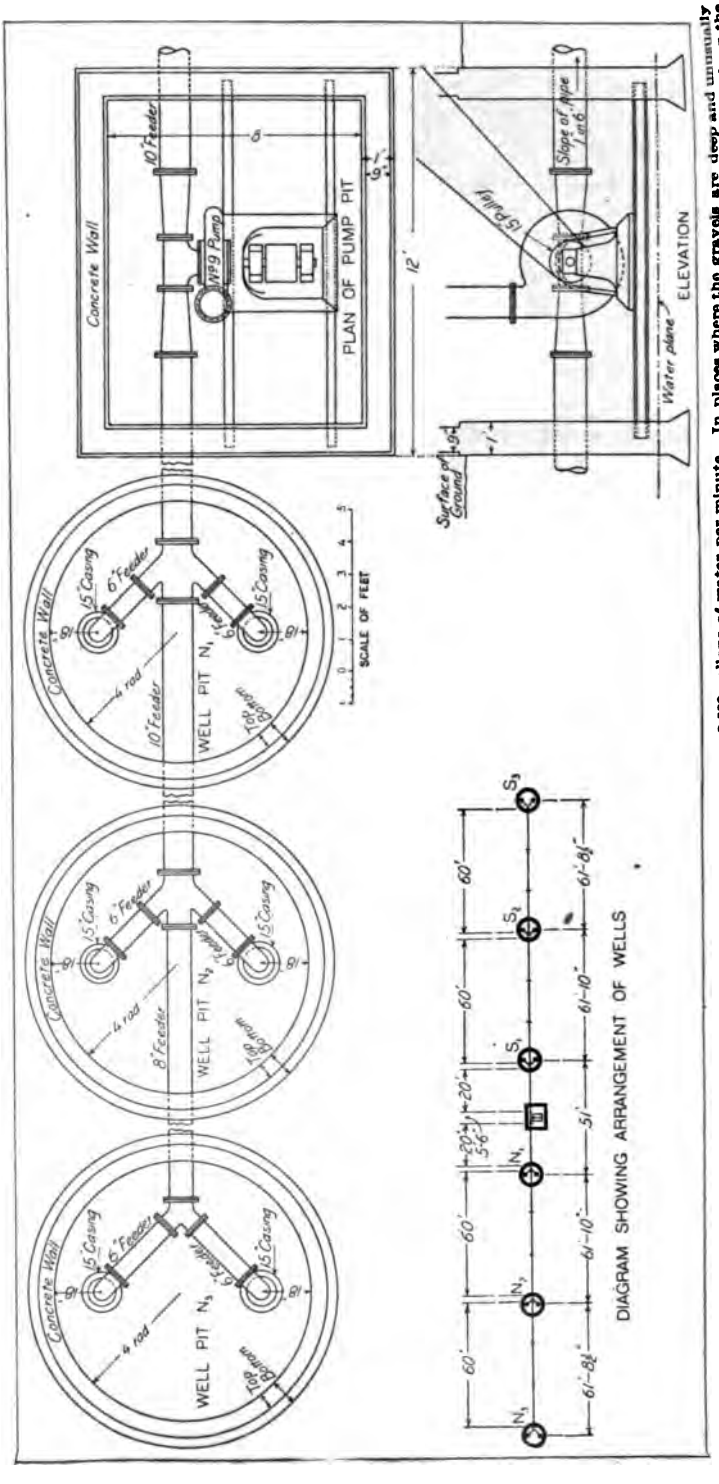


FIG. 12.—Suggested arrangement of wells and pump for a plant designed to recover 2,500 gallons of water per minute. In places where the gravels are deep and unusually coarse the wells at the end of the line of suction pipe may be omitted. The plant consists of a central concrete pump house and a group of 12 wells arranged along the suction pipe leading to the pump. The suction pipe should be placed underground as near to the level of the ground water as practicable.

ether in pairs is for the purpose of removing a large amount e sand from the water-bearing gravel. This can be done in ke those found in the South Platte Valley by pumping vigor- m one of the pair of wells and at the same time running clear o the neighboring well. By this means it should be possible ut all the fine material between the two wells. A pumping e that shown in fig. 12 should supply from 2,500 to 3,500 f water per minute, if the water-bearing gravels are of the ally found in the South Platte Valley, without lowering the re than 10 feet.

KIND OF PUMP.

ly the most satisfactory pump for use in irrigation is the al pump. It should be remembered, however, that there at many kinds of small centrifugal pumps on the market e designed for a great variety of purposes. It does not urchase any but the very best machinery for the pumping , as poorly designed machinery soon proves too expensive. ous kinds of pumps differ greatly in this respect. The cen- ump used by the irrigator should be of the inclosed-runner vided with self-oiling bearings of the oil-ring type. There ral excellent makes of centrifugal pumps on the market, of them will do good work if the size and design of the the conditions under which it must work. The maker of p should have full information of all the conditions under is to be installed, including the distance that the pump charge the water above its outlet, also the amount of suc- he distance the water must be lifted below the pump inlet. wing points are important to those about to install pump- s:

ficiency of the centrifugal pump under actual working con- higher for large pumps than for small ones. Pumps hav- charge pipe less than 3 inches in diameter will show a low .

rifugal pump will work better and be more efficient if the the suction pipe is kept as low as possible, relative to the the discharge pipe. On this account the pump should be near the level of the water as the securing of a good foun- ill permit.

pump is to be driven by means of a belt it should be pro- ith a large pulley. The pulley usually supplied with the s so small that a great amount of slipping takes place the belt and the pulley, and the efficiency of the pump is lecreased on that account. Of course, it is necessary to

secure the proper proportion between the sizes of driving and driven pulleys, but both should be larger than are usually furnished with pumps and engines.

The suction pipe on the pump and the discharge pipe should be large. A No. 4 centrifugal pump that draws water from a single well should have at least a 6-inch suction pipe, and the discharge pipe should gradually increase from 4 inches in diameter at the discharge opening of the pump to 8 inches 3 feet above the discharge opening and continue this size until the flume or discharge conduit is reached. The discharge pipe can be made of riveted galvanized iron, and the suction pipe can be made either of standard pipe or good well casing.

A centrifugal pump loses its efficiency at once if it leaks air around the stuffing box or if there is an air leak at any place in the suction pipe. Many centrifugal pumps are now provided with a water seal around the stuffing gland that insures the absence of leaks at this point.

A good centrifugal pump with inclosed impeller or runner should show an efficiency of about 60 per cent on a 30-foot lift. Single-stage centrifugal pumps, constructed with bronze impellers, made in two pieces so that the interior could be machined and smoothed, have shown an efficiency of about 80 per cent.

METHOD OF PRIMING PUMPS.

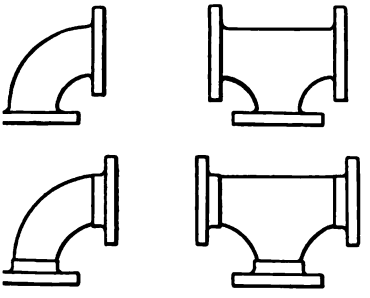
A large number of pumping plants are installed with foot valves at the bottom of the suction pipe. When these are provided a centrifugal pump is always ready to start after it is once primed. The foot valves usually interfere very materially with the flow of water into the pipe, and it is undoubtedly more economical to omit them and place a flap valve at the upper end of the discharge pipe, which can be lowered when it is desired to start the pump. An ordinary cast-iron house pump connected to the top of the casing of the centrifugal pump can be used to prime the pump with water before starting.

PIPE FITTINGS.

The suction pipe usually installed by constructors of pumping plants is not only too small for the best results, but the elbows and tees used are very poorly adapted to the purpose intended. It is a common practice to use steam-pipe fittings for this purpose. In consequence the water is required to turn at sharp angles at the tees and elbows and the best results can not be obtained. In order to avoid this difficulty "long-sweep" fittings should be purchased. These are standard trade goods and can be obtained from any of the large dealers in pipe fittings. Fig. 13 shows the difference in the two kinds of fittings.

SOURCE OF POWER.

A favorite engine for small pumping plants is the gasoline engine. here the price of gasoline is high it is very easy to make the cost water prohibitive by the use of such power. Whether or not it ys to pump water by gasoline is a matter which depends very gely on the distance the water must be lifted, but also on the id of crop that is to be irrigated. Gasoline, even at a high price, usually a cheaper fuel than coal in an ordinary steam engine of small horsepower. For plants requiring from 20 to 30 horsepower producer-gas generators can be installed, which will keep the cost of pumping down to a minimum. A suction gas producer, using anthracite pea coal for fuel, should furnish power at the rate of 1 horsepower per hour for each pound and a half of coal consumed. At $8 per ton the cost of coal should be equivalent to gasoline at 4 to 6 cents per gallon.



G. 13.—Diagram showing the relative shape of standard and "long-sweep" pipe fittings. The upper part of the diagram shows standard fittings and the lower part long-sweep fittings.

In large plants, requiring from 50 to 100 horsepower or more, a ondensing Corliss engine is sufficiently economical where the cost f coal does not exceed $3.50 to $4 per ton.

ECONOMICAL DISTANCE WATER MAY BE LIFTED.

It is very unlikely that it will pay to pump water under present onditions in the South Platte Valley, a total distance of more than 0 feet, including the suction lift of the pump. If the pump lowers he water in the wells 10 feet and if the distance to water is 10 feet elow the surface and the discharge pipe is brought into a reservoir r flume 5 feet above the surface, the total lift will be 30 feet, if 5 feet e added to cover loss of head due to friction in suction and discharge ipes. It will probably not pay to pump water to a greater height at ny place in the valley, except for the irrigation of garden truck and ther high-priced crops.

STORAGE RESERVOIRS.

In order to irrigate economically from pumping plants it is usually esirable to pump the water into a reservoir having a capacity equal the amount of water the plant can furnish in six to eight hours. ich a reservoir is absolutely necessary for the best results with

small pumping plants. If the supply of water exceeds 500 gallons per minute it is possible to dispense with the reservoir, especially if the supply greatly exceeds this amount. Plants furnishing over 1,000 gallons per minute can usually be best operated without a reservoir.

COST OF PUMPING.

The cost of recovering ground water from wells is made up of four principal items—(1) cost of fuel and supplies, (2) cost of labor, (3) charge for depreciation and repairs, (4) interest on the first cost of the plant or the capital invested. The first and third of these items are partially under the control of the owner of the plant. If the installation is carefully designed and its parts well proportioned, the cost of fuel can be kept at a minimum, and similarly the charge for depreciation and repairs will be kept low if good machinery is purchased in the first place and careful attention is given to its maintenance when in operation and when idle. The charge for depreciation will be as great, if not greater, when the plant is not running as when it is running. If the machinery is neglected and carelessly exposed when idle, the rate of depreciation will greatly exceed the rate when it is in use. The charge for depreciation and repairs should not be estimated at less than 10 per cent of the first cost of the plant.

Table VI gives an estimate of approximate cost for fuel and maintenance of a pumping plant having a capacity of 1,000 gallons of water per minute for total lifts of 10, 20, and 30 feet. In column 2 of this table is given the hydraulic horsepower, which is the theoretical power required to lift the given quantity of water the distance stated in column 1. The actual brake horsepower of the engine should be about double the amount given in column 2. The horsepower required by the engine is stated in column 3 in two ways—first, the amount of power that would be required in a well-designed pumping plant, where care has been given to all the matters previously referred to, such as the use of large suction and discharge pipes and proper selection of pump and machinery. The best that can be expected of a small pumping plant is to recover 50 per cent of the power delivered to the belt by the engine as useful work in lifting the water. The losses that occur will consist of losses in the belt, amounting to from 5 to 10 per cent, losses in the pump, amounting to about 40 per cent, and friction losses in the suction and discharge pipes, varying from 5 to 20 per cent. In order to secure an economically running plant it is important that the engine should be large enough to do the work but at the same time not too large. Great losses occur in gasoline engines if their capacity is largely in excess of the work required. The horsepower stated as a maximum in column 3 indicates the largest that should be used for the given lift.

TABLE VI.—*Approximate cost of fuel required to pump 1,000 gallons of water per minute, for various lifts.*

1.	2.	3.		4.	5.	6.	7.	8.
Total lift.	Hydraulic horsepower.	Engine brake horsepower.		Cost per hour of fuel, with gasoline at 16 cents per gallon	Cost per hour of fuel, with gasoline at 20 cents per gallon.	Cost per hour for coal at $8 per ton in suction gas-producer plant.	Cost per hour for coal at $4 per ton in condensing steam engine.	Cost of depreciation and repairs on machinery, etc., per year.
		Minimum.	Maximum.					
Feet.				*Cents.*	*Cents.*	*Cents.*	*Cents.*	*Dollars.*
10	2.8	6	7	11.2	14	4.2	6	70
20	5.6	11	14	22.4	28	8.4	12	140
30	8.4	16	21	33.6	42	12.6	18	210

NOTE.—One thousand gallons of water per minute pumped continuously for eleven hours is equivalent to 2 acre-feet of water.

In columns 4 and 5 the cost of fuel for delivering the horsepower stated in column 3 is expressed in cents per hour, based on the price of gasoline indicated in these columns. In column 6 is given the cost of fuel if hard coal costing $8 per ton be used in a suction producer-gas plant. In column 7 is given the cost of fuel per hour if soft coal at $4 per ton be used in a condensing Corliss engine. In column 8 is given a rough estimate of the cost per year for depreciation and repairs on a well-constructed plant.

In order to determine approximately the cost of pumping water any distance between 20 and 30 feet, a proportional part of the cost for 10 feet can be added to the cost for 20 feet. Thus, to get the cost of pumping water a distance of 25 feet, half of the numbers in the first line of the table can be added to those in the second line. The table should be used for estimating the cost of pumping water only for lifts lying between 20 and 30 feet. The cost for 10 feet is given for the purpose of making estimates, but it should not be supposed that the cost for this low lift would be merely half of that for the 20-foot lift, as friction and other losses would tend to make the cost for the low lift higher than that stated in the table.

Tests of a number of pumping plants in the Rio Grande Valley are reported in Water-Supply and Irrigation Paper No. 141. On page 34 of that paper will be found a table giving the fuel cost, interest, and labor cost estimated for each acre-foot of water recovered. Similar facts concerning the cost of pumping water in existing small pumping plants in the Arkansas River Valley in western Kansas will be found in Water-Supply and Irrigation Paper No. 153. A table summarizing the results is given on page 55 of that paper, and on page 82 will be found a test of a producer-gas pumping plant at Rocky Ford, Colo.

At almost any point in the river valleys of the western plains complete pumping plants, including wells, machinery, and buildings, can be constructed for about $100 per horsepower required. In some exceptional cases the cost may run as low as $60 per horsepower.

APPENDIX.

In the following tables are given statistics of wells in the territory along the line of the Union Pacific Railroad in the South Platte Valley from North Platte to Sidney, Nebr., and from Julesburg to Sterling, Colo., which have been drilled for the purpose of obtaining a water supply for private individuals and for the railroad. This information was obtained through the courtesy of the engineering department of the Union Pacific Railroad.

TABLE VII.—*Statistics of wells along the line of the Union Pacific Railroad in western Nebraska and eastern Colorado.*

Locality.	No. of well.	Diameter.		Depth.	Average consumption per day.	Normal depth to water.	Depth to water when pumping.	Strainers.
		Ft.	*in.*	*Feet.*	*Gallons.*	*Feet.*	*Feet.*	
North Platte	1		6	94				
Do	2		6	94				
Do	3		6	94				
Do	4		6	84				
Do	5		6	88				
Do	6		6	92				
Do	7		6	92	216,100	.....	.....	Cook.
Do	8		6	92				
Do	9		6	92				
Do	10		6	92				
Do	11		6	92				
Do	12		6	92				
Horshey			6	48	[a]120,000	3	12	Cook No. 8, 5½ inches by 12 feet.
Do		[b]13	0	13		6	.....	
Paxton		[c]10 / [d]9	6 / 6	15.5	34,100	4.9	8	
Oga'alla	1		6	75	51,300	5.5	30	Cook No. 8, 4½ inches by 14 feet.
Do	2		5¼	75		5.5	30	
Do	3		5½	75	[a]194,400	5	30	Cook No. 8, 5 inches by 12 feet.
Do	4		5½	75		5.5	30	
Do	5		5½	75		5.5	30	
Big Spring		12	0	13.2	.....	4.6	6	
Julesburg		12.2		17	64,500	7.6	14	
Chappell		12	6	28.5	10,000	22	24	
Lodgepole		9	6	17.5	15,000	12.5	16	
Sidney	1	[c]12 / [d]11	0 / 0	33	107,800	27	([e])	
Do	2	16	0	40	.....	27	([e])	
Sterling		[f]6	5	600	32,000	.....	.....	Cook, from 90 to 110 feet.
Do		[g]11	0	15.5	.....	7	.....	
Iliff		11	0	15.5	6,500	8	.....	
Crook		15	6	16	.....	7.3	.....	
Sedgwick		11	0	18	3,000	.....	8	

[a] Estimated flow.
[b] Old well (dug); used for emergencies only.
[c] Top.
[d] Bottom.
[e] Pumps dry.
[f] Artesian well. Casing, 90 feet 6-inch; 20 feet 5½-inch; 300 feet 5-inch; 190 feet uncased (diameter 5 inches.
[g] For emergencies only.

[Parts per million.]

Locality.	Source.	Date.	Oxides of iron and alumina (Fe_2O_3+Al_2O_3).	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Probable incrusting solids.	Total mineral solids.
Big Spring	Well 13 feet deep	Feb. 27, 1902	.....	40	42	6.9	10	4.2	26	74	172	202
Do.	do	Sept. 21, 1904	2.6	46	40	9.7	10	8.3	16	80	180	215
Chappell	Dug well 28 feet deep	Mar. 4, 1902	2.7	51	52	10	39	6.1	36	127	222	326
Do.	do	Sept. 22, 1904	1.9	54	64	13	38	12	41	141	261	367
Crook	Well 15 by 20 feet	Aug. 8, 1902	4.4	21	77	22	106	64	274	82	348	653
Hersey	New well 6 inches by 48 feet	Mar. 15, 1902	4.3	30	99	19	43	25	223	91	412	535
Do.	do	Sept. 20, 1904	1.7	20	98	17	55	24	224	100	390	550
Iliff	Well 12 by 18 feet	Oct. 1, 1902	6.3	27	271	61	273	74	982	235	1,114	1,930
Do.	Test well 1¼ inches by 19 feet; 617 feet east of water tank.	Aug. 2, 1904	.....	42	255	82	593	76	1,430	382	882	2,865
Do.	Test well 1¼ inches by 17 feet; 300 feet west of water tank.	Aug. 1, 1904	.....	62	236	60	457	30	1,191	327	885	2,284
Do.	Well, present supply	Aug. 30, 1904	3.8	26	259	66	383	73	1,249	204	1,108	2,217
Julesburg	Dug well 17 feet deep	Feb. 27, 1902	3.6	49	68	12	36	18	71	120	271	368
Do.	Well 12 by 20 feet	Feb. 23, 1903	1.5	49	78	16	41	23	106	122	321	477
Do.	do	Nov. 4, 1905	1.4	51	65	12	40	19	66	123	260	[a] 335
Lodgepole	Private well 6 inches by 51 feet	Feb. 28, 1902	2.0	56	51	11	28	7.2	21	120	230	[b] 383
Do.	Test well 6 inches by 57 feet	Mar. 22, 1902	3.8	65	49	12	48	20	47	119	235	319
Do.	Well 18 feet deep	Feb. 28, 1902	3.4	55	50	11	31	12	33	115	225	360
Do.	do	Sept. 21, 1904	1.2	65	60	13	34	10	30	137	261	300
North Platte	North Platte River, east side	Jan. 3, 1901	5.1	42	63	13	29	13	85	99	261	351
Do.	Judge Peaniston's well	do	.....	50	41	9	24	15	51	72	190	245
Do.	South Platte River	Jan. 14, 1901	.....	16	105	36	101	33	405	98	497	763
Do.	Wells at round house, present supply	Aug. 27, 1901	6.5	52	54	11	48	28	117	74	252	339
Do.	North Platte River (filtered sample), at railroad bridge, east of station.	Mar. 28, 1902	7.3	33	61	15	43	24	116	91	267	398
Do.	Wells at round house	Apr. 30, 1903	4.4	49	77	15	54	34	156	98	332	488
Do.	do	Nov. 4, 1905	1.4	51	72	16	69	31	182	100	309	[c] 527
Ogalalla	Dug well 12 feet deep	Feb. 27, 1902	1.3	27	98	24	102	25	361	93	425	731
Do.	South Platte River, south of station	Mar. 20, 1902	1.3	24	116	38	105	35	417	116	540	853
Do.	Test well 6 inches by 23 feet	Mar. 18, 1902	19	37	66	14	59	22	201	66	309	484
Do.	Test well 6 inches by 50 feet	do	3.8	56	50	10	22	13	45	93	228	294
Do.	New well 6 inches by 76 feet	Mar. 19, 1902	3.9	51	51	9.7	29	7.3	65	91	223	309
Do.	New well 6 inches by 75 feet	Apr. 25, 1902	.....	47	45	11	15	4.7	31	91	199	245
Do.	New well 5½ inches by 75 feet	Aug. 1, 1902	2.0	46	44	10	28	9.7	31	100	198	274
Do.	do	do	7.3	56	46	11	31	12	39	104	220	307
Do.	Fire wells	June 21, 1904	.....	43	54	14	21	18	65	88	242	303

[a] NO_3=10. [b] Organic matter=17. [c] NO_3=7.9.

TABLE VIII.—*Analyses of waters along the line of the Union Pacific Railroad in western Nebraska and eastern Colorado*—Continued.

[Parts per million.]

Locality.	Source.	Date.	Oxides of iron and alumina (Fe_2O_3+Al_2O_3).	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Probable incrusting solids.	Total mineral solids.
Paxton	Dug well 15 feet deep	Mar. 13, 1902	3.4	20	140	34	129	47	519	106	616	999
Do.	2-inch well at schoolhouse, one-half mile from tank.	do	4.2	26	55	10	23	18	90	66	226	293
Do.	South Platte River, 1,000 feet south of track	do	10.4	40	119	41	118	57	435	125	623	947
Do.	North Platte River (filtered sample), 4 miles north of station.	Mar. 29, 1902	8.0	39	58	14	30	10	103	84	259	346
Do.	New well	Oct. 4, 1903	8.5	45	130	36	117	46	531	66	635	979
Do.	do	Oct. 2, 1905	1.5	26	82	19	70	29	243	88	352	[a] 567
Do.	do	do	.34	22	82	19	73	29	251	85	345	[a] 570
Do.	do	Nov. 4, 1905	2.3	43	157	43	205	62	576	194	657	[a] 1,294
Sedgwick	Well 11 by 18 feet	Aug. 11, 1902	6.5	42	101	23	79	33	287	102	440	674
Sidney	Tank, source unknown	Sept. 15, 1897	[b] 6	48	84	21	25	38	95	117	371	434
Do.	Dug well 33 feet deep	Feb. 28, 1902	2.1	60	47	12	3	5	36	79	236	245
Do.	Dug well 35 feet deep	Mar. 22, 1903	2.2	61	47	12	23	13	36	99	226	293
Do.	New well 16 by 37 feet	Mar. 25, 1903	7.5	54	57	13	11	10	41	94	257	288
Do.	do	Nov. 8, 1905	.....	67	60	17	30	14	71	123	292	388
Sterling	J. M. Judd's well, 140 feet deep	May 14, 1901	2.1	22	35	10	118	67	65	134	147	453
Do.	Flowing well	July 25, 1901	6.5	23	8	3.7	565	348	18	451	64	[c] 1,462
Do.	New well 700 feet deep	Aug. 8, 1901	2.2	5.9	3.2	.....	618	436	20	428	16	1,514
Do.	Well 6 inches by 600 feet	Oct. 1, 1902	3.3	34	86	24	279	118	460	167	354	1,111

[a] NO_3=10. [b] FeO_3. [c] Organic matter=38.

INDEX.

Page.

its at Ogalalla, Nebr., extent 10
y, character of..... 6-7
ound water..... 12-15, 39-40
well and river, along Union cific Railroad..... 39-40
ley, pumping plant in, dia- ram of..... 31
in Birdwood Creek region... 27-28
near Sterling, Colo..... 8
br., well at, statistics of..... 38
at, analyses of..... 39
ek, Nebr., springs and arte- n water of..... 26-28
low, failure of, for irrigation rposes..... 22-23
r., well at, statistics of..... 38
at, analyses of..... 39
ses of ground water... 12-15, 39-40
vell at, statistics of..... 38
at, analyses of..... 39
ns., evaporation experiments 20
vial, character of..... 6-7
ern Nebraska..... 15
from Hollingsworth ditch, alalla..... 19-20
ts on, at Deerfield, Kans..... 20
or pumping..... 37
ver channel..... 6
r-bearing..... 6-8
r, amount of, obtainable by mping..... 29-30
a, dissolved solids in..... 10, 12-13
y of..... 11, 12
ng, recovery of..... 8
plane at North Platte, Nebr. 23-24
a, position of..... 10
r., well water at, analyses of . 39
tatistics of..... 38
ditch at Ogalalla, cost of.... 21
on from..... 19-20
..... 16-18
..... 17
ll at, statistics of..... 38
at, analyses of..... 39
mp, kind of, for efficient work 33
cost of..... 36-37
nical distance water can be ted..... 35
plants elsewhere, tests of..... 37
ttings in, best kind of..... 34
for, best source of..... 35
eservoirs, when desirable..... 35
recovery of, by wells..... 7

Page.

Irrigation plant, wells for, economical arrangement of..... 30-33
Irrigation works in the valley..... 6
Julesburg, Colo., well at, statistics of..... 38
well water at, analyses of..... 39
Location of the investigations..... 5-6
Lodgepole, Nebr., well at, statistics of..... 38
well water at, analyses of..... 39
Lodgepole Creek, irrigation from..... 6
North Platte, Nebr., city waterworks pumping plant, investigations at..... 25-26
ground and river waters near, analyses of..... 14
investigations at..... 23-28
well and river water at, analyses of..... 39
wells at, statistics of..... 38
North Platte River, water of, analyses of . 13, 14, 39, 40
Ogalalla, Nebr., ground and river waters near, analyses of..... 13
investigations at..... 5, 9-23
underflow ditch at, investigations on... 15-20
well and river water at, analyses of 39
wells at, statistics of..... 38
Ogalalla formation, character of..... 5-6
Paxton, Nebr., ground waters near, analyses of..... 14
well at, statistics of..... 38
well and river water at, analyses of..... 39
Pipe fittings, best kind of, for pumping plants..... 34
Power for pumping plants, best source of.. 35
Precipitation in western Nebraska..... 15
Pumping, cost of..... 36-37
economical distance water can be lifted. 35
fuel, cost of, for pumping..... 37
Pumping plant at Johnson ranch, near Sterling, defects of..... 8
in Arkansas Valley, diagram of..... 31
Pumping plants at Rocky Ford, Colo., tests of..... 37
in Arkansas River Valley, tests of..... 37
in Rio Grande Valley, tests of..... 37
pipe fittings in, best kind of..... 34
power for, best source of..... 35
suggestions for construction of small.. 29-37
Pumps, kind of, for efficient work in irrigation..... 33
priming with water, method of..... 43
Rainfall in western Nebraska..... 15
Reservoirs, storage, when desirable..... 35
Sand and silt, occurrence of, at only one place..... 7-8
Sand-hill area in western Nebraska, character of..... 15
Sedgwick, Colo., well at, statistics of..... 38

Page.

Sedgwick, Colo., well water at, analysis of..... 40
Sidney, Nebr., well water at, analyses of..... 41
wells at, statistics of..... 38
Silt and sand, occurrence of, at only one place..... 7-8
South Platte River, water of, analyses of.. 39, 40
South Platte Valley, cross section of..... 10
description of..... 5
Specific capacity of wells in South Platte Valley..... 25-26
Springs that feed Birdwood Creek, Nebr.. 27
Sterling, Colo., conditions at..... 8-9
ground and river waters near, analyses of..... 13
well water at, analyses of..... 40
wells at, statistics of..... 38
Storage reservoirs, when desirable..... 35
Underflow at Ogalalla, quantity of..... 12

Page.

Underflow at Ogalalla, velocity and direction of..... 9-12
Underflow canals, disadvantages of..... 22-23
failure of, for irrigation purposes..... 22-23
Underflow ditch at Ogalalla, investigations on..... 15-21
Union Pacific Railroad, well and river water along, analyses of..... 39-40
wells along, statistics of..... 38
Vegetation, water required by, amount of.. 19-20
Water plane at North Platte, Nebr., slope of..... 23-24
at Ogalalla, Nebr., position of..... 10
Wells along Union Pacific Railroad, statistics of..... 38
battery of, and pumps, arrangement of. 32
economical arrangement of, for irrigation plant..... 30-32
in South Platte Valley, specific capacity of..... 25-26
kind of, adapted to South Platte gravels 29

SIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 184.]

ıe serial publications of the United States Geological Survey consist of (1) Annual ›rts, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral ›urces, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United ›s—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios eof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others listributed free. A circular giving complete lists can be had on application.

ost of the above publications can be obtained or consulted in the following ways:

A limited number are delivered to the Director of the Survey, from whom they be obtained, free of charge (except classes 2, 7, and 8), on application.

A certain number are delivered to Senators and Representatives in Congress for ribution.

Other copies are deposited with the Superintendent of Documents, Washington,).., from whom they can be had at practically cost.

Copies of all Government publications are furnished to the principal public aries in the large cities thruout the United States, where they can be consulted :hose interested.

he Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of jects, and the total number issued is large. They have therefore been classified › the following series: A, Economic geology; B, Descriptive geology; C, System- geology and paleontology; D, Petrography and mineralogy; E, Chemistry and 'sics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water stor- ; K, Pumping water; L, Quality of water; M, General hydrographic investiga- ıs; N, Water power; O, Underground waters; P, Hydrographic progress reports. s paper is the twelfth in Series K and the sixty-fifth in Series O, the complete lists vhich follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES K, PUMPING WATER.

L. Pumping water for irrigation, by H. M. Wilson. 1896. 57 pp., 9 pls. (Out of stock.)
L. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls. (Out of stock.)
4. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood. 1898. 91 pp., 1 pl. (Out of stock.)
0. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls. (Out of stock.)
9. Wells and windmills in Nebraska, by E. H. Barbour. 1899. 85 pp., 27 pls. (Out of stock.)
1. The windmill; its efficiency and economic use, Pt. I, by E. C. Murphy. 1901. 72 pp., 14 pls. (Out of stock.)
2. The windmill, Pt. II [continuation of No. 11]. 1901. 73–147 pp., 15–16 pls. (Out of stock.)
1. Natural features and economic development of Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio, by B. H. Flynn and M. S. Flynn. 1904. 130 pp.
36. Underground waters of Salt River Valley, Arizona, by W. T. Lee. 1905. 196 pp., 23 pls.
41. Observations on the ground waters of the Rio Grande Valley, 1904, by C. S. Slichter. 1905. 83 pp., 5 pls.
53. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.
84. The underflow of the South Platte Valley, by C. S. Slichter and H. C. Wolff. 1906. 42 pp.

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)

WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)

WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)

WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)

WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls. (Out of stock.)

WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp. (Out of stock.)

WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls. (Out of stock.)

WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)

WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.

WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)

WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp. (Out of stock.)

WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls. (Out of stock.)

WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)

WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)

WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96-140 pp. (Out of stock.)

WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)

WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. (Out of stock.)

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.

WS 78. Preliminary report on artesian basin in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.

WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.

WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.

WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.

WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls. (Out of stock.)

WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879-1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1906. 394 pp., 34 pls.
137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.
138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.
139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.
140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.
141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 88 pp., 5 pls.
142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.
145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.
148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.
149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.
46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls.
S 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.
S 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.
S 155. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906. 83 pp., 9 pls.
S 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.
S 158. Preliminary report on the geology and underground waters of the Roswell artesian area New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.
P 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.
S 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.
P 53. Geology and water resources of the Bighorn basin, Wyoming, by C. A. Fisher. 1906. 72 pp., 16 pls.
S 160. Underground-water papers, 1906, by M. L. Fuller. 1906. 104 pp., 1 pl.
S 163. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp.
S 164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.
S 181. Geology and water resources of Owens Valley, California, by W. T. Lee. 1906. 28 pp., 6 pls.
S 182. Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 292 pp., 5 pls.
S 183. Flowing wells and municipal water supplies in the middle and northern portions of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. — pp., 5 pls.
298. Record of deep-well drilling for 1905, by M. L. Fuller and Samuel Sanford. 1906. 299 pp.
S 184. The underflow of the South Platte Valley, by C. S. Slichter and H. C. Wolff. 1906. 42 pp.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern olorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a ortion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, y Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank everett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern outh Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward rton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by H. Darton, Bulletin No. 138.

Correspondence should be addrest to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

NOVEMBER, 1906.

O

Water-Supply and Irrigation Paper No. 185 Series L, Quality of Water, 15

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

INVESTIGATIONS

ON THE

PURIFICATION OF BOSTON SEWAGE

Made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

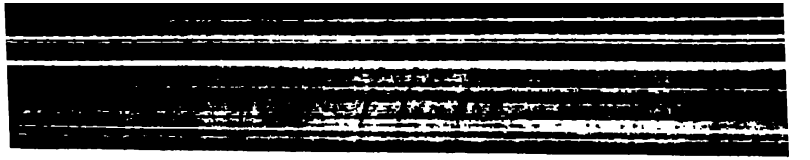
WITH A

HISTORY OF THE SEWAGE-DISPOSAL PROBLEM

BY

C.-E. A. WINSLOW AND EARLE B. PHELPS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906



CONTENTS.

	Page.
on, by William T. Sedgwick	5
the sewage-disposal problem	9
e of the problem	9
osition of sewages	13
sal of sewages by dilution in lakes, rivers, and the sea	16
sal of sewages by broad irrigation or sewage farming	24
nent of sewages by chemical precipitation	29
cation of sewages by intermittent filtration through sand	35
nent of sewages in the septic tank	42
cation of sewages by the contact process in beds of coarse material	53
cation of sewages by a continuous trickling process over coarse erial	75
t tendencies in sewage-disposal practice in England, Germany, and United States	88
ıts on the purification of Boston sewage, 1903–1905	97
ewage experiment station	97
tical methods and interpretation of results	107
cter of the crude sewage	111
val of suspended matter	114
inary treatment in the septic tank	119
cation by intermittent sand filtration	126
cation in contact beds of coarse material	132
asions bearing on the treatment of Boston sewage	147
owledgments	149
hy	149
	155

ILLUSTRATIONS.

FIG. 1. Diagram illustrating self-purification of Sudbury River .....
2. Diagram illustrating self-purification in the Thames, England.....
3. Seasonal variations in the condition of Merrimac River at Lawrence, Mass .....
4. Seasonal variation in gas production in the septic tank.....
5. Progressive effect of septic action at Lawrence, Mass.....
6. Loss in capacity of contact beds at Manchester, England.....
7. Comparison of sewages and effluents from contact beds .....
8. Comparison of sewages and effluents from trickling beds.....
9. Map of Massachusetts metropolitan sewerage district .....
10. Plan of Massachusetts Institute of Technology experiment station grounds and buildings.....
11. Detail of grit chamber.....
12. Plan of ground floor of filter house.....
13. Plan of second floor of filter house .....
14. Section of filter house .....
15. Composition of the crude sewage of Boston .....
16. Composition of septic effluents.....
17. Comparison of various forms of nitrogen in crude sewage and sand-filter effluents.....
18. Comparison of effluents from primary-contact beds of various-sized stone.....
19. Comparison of effluents from primary-contact beds of different depths .....
20. Comparison of effluents from primary-contact beds at different rates.
21. Comparison of effluents from double-contact systems taking crude and septic sewage.....
22. Comparison of sewages and effluents from single and double contact beds .....

INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE.

By C.-E. A. Winslow and Earle B. Phelps.

INTRODUCTION.

By William T. Sedgwick.

Systems of water carriage, or sewerage, are now almost universally employed for the quick and inoffensive removal of fluid wastes and human excrements from thickly settled communities. These fulfill fairly well that first and most imperative requirement of scientific sanitation—the prompt and efficient removal of the more dangerous excreta. As often happens, however, the solution of one problem has given rise to another scarcely less difficult, namely, in this case, the sanitary and economic disposal of vast quantities of contaminated liquids known as sewage. The volumes of sewage discharged by modern communities are so large, especially in the United States, where water is liberally supplied, freely used, and frequently wasted, and the character of all kinds of sewage is always so objectionable, that the so-called sewage-disposal problem becomes, from the economic as well as the sanitary point of view, one of the most serious with which modern communities have to deal. Nor is this merely a public or community problem. Isolated private houses of the better class are now almost invariably abundantly fed with running water—a supply which has become one of the greatest necessities as well as one of the greatest luxuries of civilized life. In such houses the water-carriage system for the disposal of household wastes of all kinds has found favor no less than in crowded communities. Here, also, it entails a difficult problem, i. e., the ultimate disposal of large quantities of noxious sewage; and for the house no less than for the community it is important to secure this ultimate disposal in such a way as to avoid the creation of any insanitary focus or foci in the environment, or any infringement of the laws of hygiene and sanitation.

Moved by the magnitude and gravity of the sewage-disposal problem as it concerns householders and communities, an anonymous friend of the Massachusetts Institute of Technology, in 1902, presented to that institution the sum of $5,000 a year for three years, for the purpose of making experiments on sewage purification and of giving the widest possible publicity to means or methods by which the present too often crude and imperfect systems may be improved. In a letter which constituted a virtual deed of gift, the donor designated a preference for the following lines of activity:

1. For keeping up with the investigations of the best workers in all countries.
2. For utilizing this knowledge in the work of the Massachusetts Institute of Technology.
3. For original experiments.
4. For distributing all over the country the results of the work in such words that he who runs may read.
5. For inciting students to make plain and simple statements of the results of their studies.

The gift thus made was gratefully accepted by the authorities of the Massachusetts Institute of Technology, and the planning and organization of the work to be done were assigned by them to the writer, head of the department of biology, who had for some years served as lecturer in the Institute on sanitary science and public health, and had also gained considerable experience in sewage purification during connection of several years with the work of the State board of health of Massachusetts. In view of the limited means available and the long-continued and well-known investigations of the Massachusetts State board of health at the Lawrence experiment station, dealing chiefly with the sewage of an inland city; in view, also, of the increasing use of harbors for the disposal of the sewage of seaboard towns, with the growing dangers of contamination of shellfish, pollution of bathing beaches, and the like; and especially in view of the desirability of making the new work of practical educational value to the students of the Institute of Technology, who might carry away with them into active life and to all parts of the country the results of personal knowledge of the work, it was decided to establish a sanitary research laboratory and sewage experiment station on the main trunk sewer of the south metropolitan system of the great seaboard city of Boston. The precise point finally chosen, near the corner of Massachusetts avenue and Albany street, has proved very convenient and favorable. Here a piece of land formerly occupied by a livery stable was secured on a long lease, the stable itself was turned into a tank house, and a smaller building on the premises was fitted up as an office, with chemical and bacteriological laboratories connected. Open space enough remained for the construction later of outdoor filters and a large trickling filter. Permission was obtained for making connections with the main trunk sewer of the south metropolitan

em on its way to the sea at a point where it contained the sewage contributing population of about half a million people, and for ving sewage from this sewer as needed. A pump was installed, ts were constructed for tests of various methods of sewage purifi- on, and a working organization was effected by the formal pointment of the writer as director, of C.-E. A. Winslow as biologist harge of the laboratory and station, and of Earle B. Phelps, a luate of the Institute in the department of chemistry, and for some s assistant at the Lawrence experiment station of the Massa- setts State board of health, as research chemist and bacteriologist. ll description of the laboratory and experiment station is given pages 97–107, illustrated by figs. 10–14.

he elaborate and long-continued experiments of the State board ealth of Massachusetts at the Lawrence experiment station on rmittent sand filtration as a means of sewage purification made lvisable to set up only three filters of this kind, largely for demon- tion purposes and for the benefit of students. To the so-called ic-tank method it was felt necessary to give somewhat more atten- , the value of this process under various conditions being still ewhat problematical; and to the contact system much attention given for the same reason. More recently, continuous filtration neans of trickling filters has come to the front, particularly in land, and this system of disposal has therefore required especially ful consideration and study.

s a prerequisite for all these investigations it was plainly necessary ake, in the first place, careful examinations of the character and unt of the sewage actually discharged by the south metropolitan em of Greater Boston. The results of these examinations have ady been published, together with other papers, in vol. 1 of "Con- itions from the Sanitary Research Laboratory and Sewage Experi- t Station of the Massachusetts Institute of Technology," of ch the present work is volume 2. Volume 1 appeared originally ne "Journal of Infectious Diseases," volume 1, supplement No. 1, ago, 1905, and was also reprinted as a separate brochure. This er was in large demand and is now unfortunately out of print, a limited number of the copies of the "Journal of Infectious ases" containing these papers may still be purchased from publishers. As a matter of record the titles of the papers may be given, as follows:

chemical and bacterial composition of the sewage discharged into Boston Harbor the south metropolitan district. C.-E. A. Winslow and E. B. Phelps.

number of bacteria in sewage and sewage effluents determined by plating upon differ- edia and by a new method of direct microscopic enumeration. C.-E. A. Winslow.

mode of action of the contact filter in sewage purification. E. B. Phelps and F. ll.

A critical study of the methods in current use for the determination of free and albuminoid ammonia in sewage. E. B. Phelps.

The determination of the organic nitrogen in sewage by the Kjeldahl process. E. B. Phelps.

Test of a method for the direct microscopic enumeration of bacteria. C.-E. A. Winslow and G. E. Willcomb.

The present volume contains, first, a careful and elaborate historical review of the whole sewage-disposal problem from its origin in the wide adoption of the water-carriage system up to the present time, when that system has become practically universal. This interesting review can not fail to be of the highest value to expert engineers, sewage commissioners, and communities all over the United States, especially those numerous small communities which are confronted, perhaps for the first time, with a problem which means so much for the health as well as the finances of the citizens.

Following the historical review is a full description of the experiments thus far made on the sewage of a great American seaboard city, together with comparisons with similar work done elsewhere, with practical conclusions which have been drawn from the experiments and specific statements concerning the comparative merits of various systems of purification tested. These are by no means applicable merely to large cities or to seaboard cities, but contain lessons of practical value for all sorts of communities having to deal with the ever present sewage-disposal problem.

This report is by no means final, for experiments are still in progress not only along these lines but also along others more recently developed. In particular, the percolating, trickling, or continuous filter method is being more extensively tested, with results which it is hoped may be ready for publication by the end of another year.

The donor of the original gift has consented to continue the work for the fourth and fifth years—an immense advantage in work of this kind, which grows in interest and value with the lapse of time as well as with the experience gained by the workers on the problems involved. In consonance with the wishes of the donor as expressed in the deed of gift, it is the intention of the director to prepare a brief popular statement of the facts contained in this volume, in language so simple that citizens, boards of health, and sewerage commissions may readily avail themselves of the information here contained, and so that, as desired by the donor, "he who runs may read."

The work here described and the results here recorded have no connection with the well-known work of the State board of health of Massachusetts and no official connection with the city of Boston or any of its departments. They proceed entirely from an educational institution—the Massachusetts Institute of Technology—and all the

ers and workers at the laboratory and station have been either ers, graduates, or students of the Institute.

, however, as is quite within the bounds of possibility, it should become necessary to purify the sewage of Greater Boston, or of part of it, before discharging it into the waters of Boston Harbor, e is reason to believe that these studies may have a practical local ie in proportion to their cost. Meantime, it is the wish of the ctor no less than of the donor that they may be found immedi- y serviceable to numerous American communities confronted with sewage-disposal problem and seeking means for its solution.

ı addition to those persons already mentioned, the working staff he laboratory and station has included, for longer or shorter peri- Prof. S. C. Prescott, of the Massachusetts Institute of Technology; f. E. G. Smith, of Beloit College; Miss Anne F. Rogers, and Messrs. rge R. Spalding, Frederick W. Farrell, George C. Bunker, George Villcomb, James A. Newlands, William H. Beers, and William T. penter, all of whom have contributed directly or indirectly to the ussions and results contained in this volume.

ASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Boston, April, 1906.

ISTORY OF THE SEWAGE-DISPOSAL PROBLEM.

NATURE OF THE PROBLEM.

he disposal of waste is a fundamental problem for all living nisms. As the body takes in food and builds it up into its own iliar structure, so it must continually break down and give off te products, which, as a rule, if they accumulate, prove poisonous ie organism itself. This is the case with the individual; it is still e the case when large numbers of organisms are closely congre- d together in communities. The political body resembles the nisms of which it is composed in no merely fanciful sense. It is ect to the laws of organic life; it has its income and its outgo; and lure to remove the waste products of its life processes is inevitably gerous to the units of which it is composed.

ı spite of these facts, the attempt at scientific waste disposal is paratively recent. The Cloaca Maxima and the other so-called rs of antiquity were rather drains than sewers, and their function to lower the ground-water level and not primarily to remove etal wastes. Until 1815 the discharge of any waste but kitchen ; into the drains of London was prohibited by law, and the same lation persisted in Paris up to 1880. Sewerage and sewage di

posal proper really date from the epoch-making report of the of towns commission of Great Britain in 1844,[a] which revea accumulation of such an astonishing amount of decomposing matter and filth of all kinds in the cities that it aroused Briti tarians to a strong movement for the amelioration of these co and led to the development of the filth theory of disease—the that disease is bred in heaps of decomposing filth. This pyt theory of Chadwick and Murchison we now know to be wro essential assumption that infective material is created de n decaying organic matter; yet it was right in laying emphasis as a carrier of disease. The wonderful administrative work British sanitarians, acting on this partially erroneous theory, the greatest sanitary progress which has probably ever been Public and private cleanliness was taught and practiced a before. The midden system and the pail system rapidly gave the water-carriage system. Whereas in 1815 the sewers of were simply drains to carry off the storm water—the discharge age into them being forbidden by law—in 1847, only three yea the report of the health of towns commission, it was made ob to discharge all sewage into those drains.

In other countries the example set in England was more promptly followed. In the United States numerous drains tems existed, one in Boston, for example, dating from the seve century; but the first comprehensive sewerage project was d

[a] Frequent reference will be made to the investigations of the royal commissions of Gre and in order to avoid confusion the following chronological summary of the work of those c which have dealt with sewage disposal and allied subjects is quoted from A. J. Martin:

1843. Royal commission appointed "to inquire into the present state of large towns and po tricts" (health of towns commission).
1844. First report of health of towns commission.
1845. Second and final report of health of towns commission.
1857. Royal commission appointed to inquire as to the best means of distributing the sewa (sewage of towns commission).
1858. Preliminary report of sewage of towns commission.
1861. Second report of sewage of towns commission.
1865. Commission appointed to inquire in the best means of preventing the pollution of ri pollution commission).
Third report of sewage of towns commission.
1868. Second rivers pollution commission appointed.
1870. First and second reports of rivers pollution commission.
1871. Third report of rivers pollution commission.
1872. Fourth and fifth reports of rivers pollution commission.
1874. Sixth and final report of rivers pollution commission.
1882. Commission appointed to inquire into the effects of the discharge of the sewage of the into the river Thames (metropolitan sewage commission).
1884. First report of metropolitan sewage commission.
1885. Second and final report of metropolitan sewage commission.
1898. Commission appointed to inquire and report what methods of treating and disposing may properly be adopted (royal sewage commission).
1901-2. Interim report of royal sewage commission.
1902. Second report of royal sewage commission.
1903. Third report of royal sewage commission.
1904. Fourth report of royal sewage commission.

by E. S. Chesbrough for the city of Chicago in 1855. On the continent of Europe a sewer system was constructed at Hamburg after the great fire of 1842, by Lindley, an English engineer. Berlin began her sewerage in 1860 and other German systems quickly followed. France and the Latin countries, though still somewhat inadequately sewered, are making progress. No law of sanitation is now more clearly recognized than the principle that the wastes of human life must be diluted with an adequate supply of water and quickly removed from the region of habitation.

With the establishment of the water-carriage system the difficulty was shifted from the individual to the community. The insanitary conditions surrounding the dwelling were relieved, but at some point on the outskirts of the city the concentrated filth from its entire population must be disposed of. The vast volume of water in which the excretal elements are distributed makes the problem only more difficult. In England the average daily flow of sewage is about 25 gallons per capita. In London it is 34 gallons (R. S. C., 1902 b[a]). In the United States, on the other hand, the flow in several small Massachusetts cities is estimated at about 100 gallons (Fuller, 1903), while for the south metropolitan district of Boston it is over 250 gallons (Winslow and Phelps, 1905). In the latter case the yearly flow of sewage amounts to 46 billion gallons—a fair-sized river. The organic matter to be treated includes during the year over 1,500,000 kilograms of nitrogen in the form of free ammonia alone. The treatment of such a volume of waste material offers a problem in applied chemistry of no mean magnitude.

The undesirable constituents in sewage may be considered under two heads—living germs and dead organic matter. The first create disease; the second breeds nuisances. The germs of almost any disease of man or the lower animals may gain access to sewage, and, in the case of typhoid fever in particular, the infection may be transmitted through its agency so as to cause epidemics on a disastrous scale. The experiments of Jordan, Russell, and Zeit (1904) and of Frost (1904) indicate that typhoid bacilli in water, and particularly in sewage-polluted water, for the most part die in a few days. Yet the statistics of Lowell, Lawrence, Chicago, Philadelphia, Pittsburg, and Newark indicate that the typhoid germs which survive a sojourn in sewage and water are sufficiently numerous to produce serious results. Therefore where shellfish are taken from an estuary into which sewage is discharged it is desirable to subject the sewage

[a] Complete references to all literature cited in this report will be found in the bibliography at the end. References in the text include the name of the authority (the initials in the case of the British commissions) and the date of publication, with a distinguishing letter in case more than one volume appeared in a single year. This serves simply to identify the article or book, the full title of which is given in the bibliography.

to some process—such as sand filtration—which effects a considerable reduction in bacterial content; and the sterilization of an effluent after its complete oxidation might, under certain conditions, prove desirable. As a rule, however, if the effluent from a sewage plant as discharged into a stream is clear and nonputrescible, the process is considered to be satisfactory. It is becoming more and more clearly recognized that all polluted waters, perhaps all surface waters, should, before they are used for drinking, be treated by water filters designed for the special purpose of removing disease germs. If such filtration as this is to follow, it is unnecessary to place on the sewage-purification works the extra burden of bacterial removal. The immediate and pressing need at the sewer outfall is the disposal of the organic matter, which threatens to create a nuisance by its decomposition. This organic matter may often be rendered harmless by means quite different from those calculated to effect high bacterial removal. When such is the case, it is scarcely fair to hamper the essential task of sewage disposal by demanding a bacterial purification which can be better attained by subsequent special treatment in water filters. All sewage-purification processes, as a matter of fact, materially reduce the number of bacteria present; but this must in general be regarded as incidental, the success of the process being gaged chiefly by the fate of the organic matter.

Where the waste from manufacturing processes is abundant, certain special problems are introduced. The material to be handled may be greatly increased in amount and the added material may be organic matter of a specially refractory kind, such as is found in wool-scouring waste, tannery waste, and brewery waste. Furthermore, the presence of mineral poisons may interfere with the very processes which bring about the purification of the organic matter present. The acid-iron sewage of Worcester is an example of this sort, the biological processes of purification being appreciably hampered by the waste liquors from wire mills. The waste from the sulphite-pulp mills offers a notable example, carrying vast amounts of refractory organic matter, together with antiseptics which prevent any bacterial treatment until they are removed. Such industrial wastes require specific treatment in each case, generally along mechanical and chemical lines. They offer special problems quite distinct from the main question of sewage treatment, to which it is desired to limit the present paper.

In the disposal of ordinary domestic sewage it is primarily dead organic matter which must be dealt with. The products of the metabolism of men and animals and the partially decomposed waste materials from the preparation of food are largely made up of unstable organic compounds. They must be further decomposed, and the *decomposition* may follow either of two different courses. Under

ordinary conditions a rapid reduction of any available oxygen first takes place, followed by an incomplete anaerobic putrefaction, accompanied by the evolution of methane, carbon dioxide, nitrogen, hydrogen, and various ill-smelling gases, such as hydrogen sulphide and the mercaptans. Such a process is likely to create a nuisance objectionable from economic as well as esthetic grounds. The odors of decomposition may even become so objectionable as to menace the public health.

The history of the organic matter is quite different if its decomposition takes place in the presence of an abundant supply of oxygen. If dry organic matter is burned, it is converted into water and the oxides of carbon and nitrogen. If moist organic matter is allowed to ferment in the presence of an ample supply of oxygen, a slow oxidation is accomplished by the activity of certain micro-organisms, and the end products are again water, carbon dioxide, and nitrates. This aerobic fermentation is free from odor, and its end is the complete conversion of the decomposition products into harmless inorganic constituents. Such an oxidation alone can finally dispose of the excretal products and prevent the obnoxious conditions attendant on anaerobic putrefaction. This is the rational aim of all processes of sewage disposal, which may be defined as methods for the conversion of the waste products of organic life and death into their oxidized and mineral forms.

COMPOSITION OF SEWAGES.

Chemically considered, sewage is a dilute solution and suspension of certain organic and inorganic substances in water. The statement, originally made in 1890 by Hiram F. Mills and often quoted by subsequent writers, that "a sewage stronger than ordinary would contain, say, 998 parts of pure water, 1 part of mineral matter, and part of animal and vegetable matter," serves its intended purpose in fixing an upper limit for the constituents of sewage, but is excessive for the sewage of American and English cities in its estimate of solids. From the data available it may be stated that 800 parts per million of total solids, as against 2,000 parts given by the standard mentioned, is a liberal figure for American cities and is exceeded by few; English cities may average about twice as much, while the continental European cities vary widely, but in few cases exceed 2,000 parts.

Of the total solids in a sewage it may be said roughly that from 0 to 70 per cent is in solution, either true or colloidal, the remainder being insoluble matter in suspension. Measured by the nature of the solids, about one-half, as a rule is volatile on ignition, representing in the main organic matter, while the remainder, called the fixed solids, *represents the* mineral matter originally present, as well as

the mineral ash of the organic matter. The fact should be emphasized in this connection that many mineral substances are lost on ignition and that the combustion of nearly all organic substances occurring in nature leaves a greater or less amount of mineral ash. By far the larger part of the fixed solids is found dissolved, this amount on the average reaching about 75 per cent of the total, most of the remainder being sand or other insoluble matter, largely derived from street washings. The division of the organic matter is about equal between dissolved and suspended matter.

Concerning the character of the mineral matter present, it may be said that the portion in solution is of little consequence in relation to sewage treatment. It consists largely of sodium chloride. In certain special cases dissolved mineral matter may be precipitated during treatment and become burdensome. This is especially the case where iron salts are present in considerable amount. The insoluble mineral matter and the mineral residue from organic matter concern the present discussion more immediately, since in many processes of treatment these materials will accumulate to the detriment of filters. They normally amount to perhaps 10 per cent of the total solids and in the case of cities sewered on the separate system will not vary materially from that proportion. Combined sewers, however, admitting storm water from the streets, deliver an immense amount of sand and similar material during a storm, for the care of which some provision must be made at the disposal plant. No estimate can be made of the amount of such material likely to be delivered. It will depend entirely on local conditions, especially on the nature of the streets and the soil and on the severity of storms.

The character of the organic matter is of much greater importance. It is customary to speak of nitrogenous and carbonaceous matter, although the nitrogenous matter contains as a rule more carbon than nitrogen. Since, however, organic matter containing nitrogen gives rise on decomposition to products offensive to the senses, and since the various products of its oxidation are readily determined by simple analytical methods, much greater stress has always been laid on the nitrogen in sewage than on any other element. The total nitrogen value for American city sewages may be roughly placed at from 15 to 35 parts per million. Of this amount from one-third to one-half, depending on the condition of the sewage, will be in the form of free or saline ammonia, largely as ammonium carbonate. The remainder, say from 10 to 25 parts per million, exists in combination as organic nitrogen. The nitrogenous organic material present in part results from the breaking down of proteid or albuminous material in digestion and in part represents unaltered proteid material. Albumin contains about 16 per cent of nitrogen, while its decomposition products—leucine, tyrosine, and various other amido-acids—

ntain from 8 to 10 per cent, so that 10 per cent may perhaps be ken as an average value for the nitrogen in the nitrogenous mate-l. This gives an amount of such material equal to from 100 to 0 parts per million in the sewages under discussion. Roughly, out one-half of this nitrogenous material is carbon in organic com-nation, giving from 50 to 125 parts per million of carbon. The al carbon of such sewages may be expected to be between 100 and 0 parts, say 200 for an average, of which perhaps 75 parts are nd in the nitrogenous material. This leaves 125 parts of carbon carbonaceous (nonnitrogenous) material, of which the greater rt is cellulose or some other carbohydrate and fat. From the ther meager data available as to the amount of fat in sewage, it ay be concluded that 50 parts per million is perhaps a fair average ure. Seventy per cent of the fat, or 35 parts, is carbon, which, ducted from the 125 parts previously mentioned, leaves about 90 rts of carbon as carbohydrate. The proportion of carbon in car-hydrates being taken at 46 per cent, this gives 200 parts per mil-n of carbohydrate. The figures thus deduced may be taken as ir average figures for American sewages. Considerable variation om the estimates may be found, amounting to perhaps 50 per cent n either side, but the relative amounts seem to be fairly constant far as can be judged from available data. For the sake of clear-ss these typical figures are tabulated below:

Composition of an ideal sewage.

[Parts per million.[a]]

	Total.	In solution.	In suspension.
due on evaporation	800	500	300
eral and ash	400	300	100
an c and volatile	400	200	200
Nitrogenous	150		
Nitrogen	15		
Carbon	75		
H, O, S, P, etc	60		
Nonnitrogenous	250		
Fats, etc	50		
Carbon	35		
H, O	15		
Carbohydrates	200		
Carbon	90		
H, O, etc	110		
Total carbon	200		
Total nitrogen	15		
Total H, O, S. P, etc	185		

All analytical results in this report are expressed in parts per million. Data cited from other horities have been converted to the same basis.

In order to change these figures to grams per capita per day it is ly necessary to multiply by 0.38, a daily flow of 100 gallons per pita being assumed.

The sewage of English cities is in general stronger than the figures ven here for a typical American sewage. Analyses previously com-led (Winslow and Phelps, 1905) indicate that the total solids in

European sewages will average about 1,500 parts per million, with a range of from 500 to 2,100 parts. The organic constituents also, as measured by total organic nitrogen, indicate that European sewages are twice as strong as American. Values for oxygen consumed are not comparable on account of differences in analytical methods, but those for free ammonia are much more nearly equal in the two cases.

The amount of oxygen required to convert these organic substances into the mineral form is considerable. Dibdin, as shown in Table I, estimates it at from one to three times the weight of the organic substance to be acted on.

TABLE I.—*Parts of oxygen required to oxidize one part of various organic substances (Dibdin, 1903).*

Substance.	Oxygen required.				Oxygen already present.	Difference, or additional oxygen required for complete oxidation.
	By the nitrogen.	By the hydrogen.	By the carbon.	Total.		
Gelatin	0.523	0.528	1.333	2.384	0.251	2.133
Chondrin	.411	.568	1.310	2.289	.294	1.995
Albumen	.457	.568	1.414	2.439	.220	2.219
Cellulose, woody fiber		.496	1.184	1.680	.494	1.186
Starch		.496	1.184	1.680	.494	1.186
Fat, stearic acid		1.016	2.025	3.041	.113	2.928

The problem of sewage disposal is to supply this required oxygen and to supply it under such conditions that it will unite with the organic matter to be eliminated.

DISPOSAL OF SEWAGES BY DILUTION IN LAKES, RIVERS, AND THE SEA.

The most obvious way to dispose of sewage is to empty it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest watercourse, and when the drain became filled with polluting matter the same plan was followed. Within certain limits the process proved a success. When the volume of sewage was not too great it disappeared by dilution and was finally removed by the agencies involved in the "self-purification of streams." The dilution is, of course, only an aid to purification and not in itself an active agent in the process. A drop of ink in a barrel of water is still existent, though invisible. Sedimentation too, is scarcely in itself a process of purification, although it performs a most important part, separating the solids and storing them so that other agencies may have time to act. Oxidation of the organic matter is the real purification process, and it is by virtue of this process that streams are able to dispose of organic pollution when they do so successfully.

The oxidation of organic matter in a stream or pond may be

partly due to direct chemical action. In the main, however, it is carried out by the activity of micro-organisms. The larger microscopic forms, the crustacea, the rotifera, and the protozoa, play a part the exact importance of which is hard to estimate, especially in the consumption of the solid particles. The algæ and other green plants exercise an important influence, as shown by Bokorny (1897) and others. The chief agents, however, are the bacteria, particularly those metatrophic and prototrophic forms which liquefy proteids, liberate free ammonia from more complex compounds, and oxidize it to the mineral form.

The process of self-purification of streams, though a real process, is a slow one. The rivers pollution commission of Great Britain concluded in 1874 that sewage mixed with twenty times its volume of pure water would be two-thirds purified in flowing 168 miles at a rate of 1 mile an hour. Long, in 1889, made a careful study of this process in the Illinois and Michigan Canal. A large part of the sewage of Chicago, diluted with the water of Lake Michigan, at that time flowed through the canal for a distance of 29 miles at a rate of about 1 mile an hour. Analyses from Bridgeport and Lockport, at the beginning and end of the canal, as shown in Table II, gave a purification of 23 per cent as measured by albuminoid ammonia and 27 per cent measured by oxygen consumed, with a removal of 46 per cent of the matter in suspension.

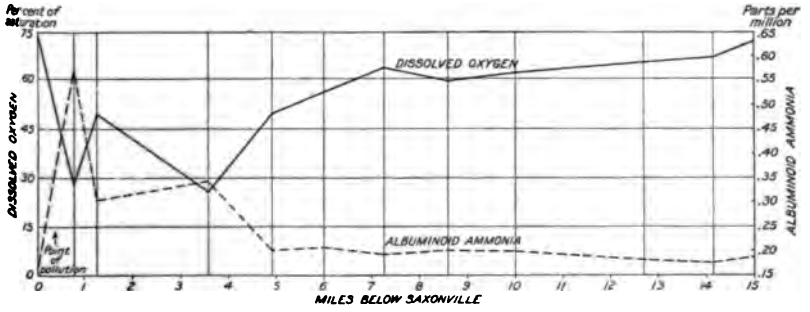


FIG. 1.—Diagram illustrating self-purification of Sudbury River.

TABLE II.—*Analyses of water from the Illinois and Michigan Canal at Bridgeport and Lockport (Rafter and Baker, 1894).*

[Parts per million.[a]]

Place collected.	Total solids.	Matter in suspension.	Nitrogen as nitrates.	Chlorine.	Hardness ($CaCO_3$).	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Oxygen consumed.
Bridgeport	471.2	129.2	0	46.8	201.3	10.1	2.1	22.1
Lockport	431.2	69.8	0	46.1	207.7	8.9	1.6	16.2

[a] Free and albuminoid ammonia values throughout this paper are expressed as nitrogen. The method by which oxygen-consumed determinations were made is stated whenever it could be ascertained from the original reports.

Streams with more sluggish flow will naturally exhibit a greater purification in a short distance, since sedimentation will be greater and since the time during which the nitrifying organisms act is one of the chief factors involved. Sudbury River in Massachusetts, for example, is heavily polluted at Saxonville by the wastes from a woolen mill. It flows rapidly for about 3 miles below the mill and then enters an area of meadows where it winds along through a weedy channel at a rate not more than one-fourth mile an hour. In an investigation by Woodman, Winslow, and Hansen (1902) it was found that 3 miles below the entrance to the meadows and 6 miles below the mill the chemical constituents of the stream had fallen to their normal. The relations of albuminoid ammonia and dissolved oxygen on one of the days studied is indicated in fig. 1, in order to illustrate the progress of the purifying process. It will be noticed that below the point marked "Point of pollution" the albuminoid ammonia is greatly increased, and the dissolved oxygen, being absorbed by the organic matter, is correspondingly diminished. Gradually, however, normal conditions reassert themselves, more oxygen is absorbed, and the albuminoid compounds settle out and are oxidized. At the station 6 miles below the point of pollution both constituents have been restored to their original value. Throughout, the reciprocal variation of the oxygen and the oxidizable nitrogen are striking.

Next to the time element the amount of available dissolved oxygen is, as this diagram suggests, the chief condition for the purification process; and the whole history of the pollution and self-purification of streams may be traced by the diminution and gradual restoration of this constituent. Dibdin's studies of the Thames below London are most significant in this respect and illustrate on a practical scale the enormous volumes of the oxidizing agent needed. He estimates (Dibdin, 1904) that 2,000 tons of oxygen are absorbed by the river between Teddington and Southend in this process. The proportion of dissolved oxygen, expressed as "Per cent of saturation," at various points along the river on the high tide is plotted in fig. 2 from figures given by Dibdin (1904) for 1893–94. As the river enters the city between Kew and Battersea its oxygen content falls from 70 per cent to 43 per cent, and the progressive pollution continues until at Woolwich the oxygen value is only one-fifth that of saturation. Below Barking Creek the heavy pollution ceases, absorption of oxygen overbalances its consumption, and the normal conditions are gradually restored. The same general relations are shown in Table III, quoted by the Connecticut State sewage commission (1899). The ratio of oxygen to nitrogen, which changes from 1:2 at Kingston, above London, to 1:62 at Greenwich, is most significant.

—*Dissolved gases in the Thames above and below London, England (Connecticut, 1899). Analyses by Roscoe and Schorlemmer.*

[Cubic centimeters per liter.]

	Kingston.	Hammersmith.	Somerset House.	Greenwich.	Woolwich.	Erith.
e of gas	52.7	.....	62.9	71.25	63.05	74.3
de	30.3	.....	45.2	55.6	48.30	57.0
	7.4	4.1	1.5	.25	.25	1.8
	15	15.1	16.2	15.4	14.5	15.5
gen to nitrogen	1:2	1:3.7	1:10.8	1:62	1:58	1:8.6

in any river the proportion of organic matter is slightly l over that in the Thames at Woolwich, the small proportion ved oxygen may be quite consumed. Conditions change and

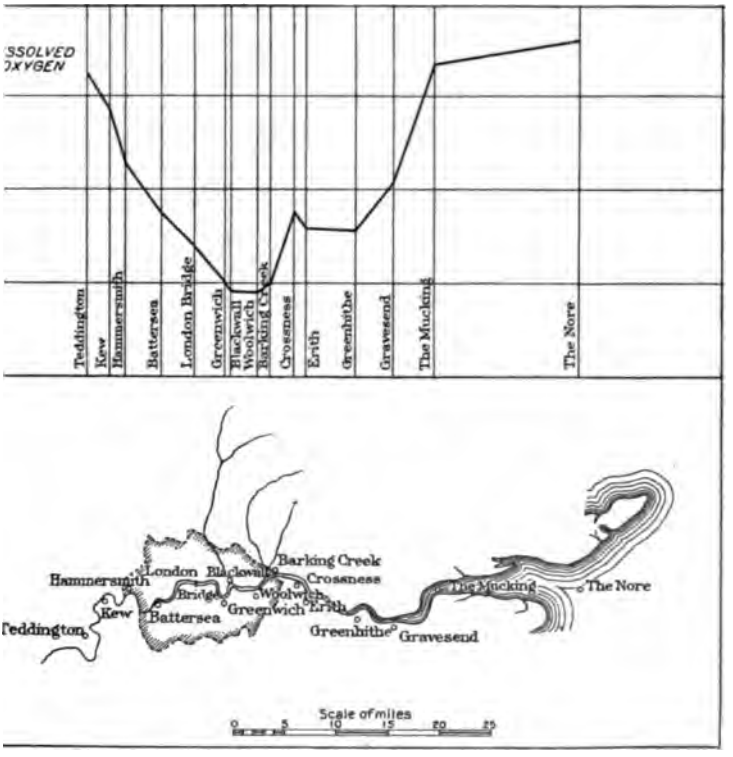


FIG. 2. Diagram illustrating self-purification in the Thames, England.

of aerobic nitrification, anaerobic putrefaction is set up. elling gases are produced, and in place of a self-purifying ı septic tank or open cesspool is produced.

is evidently a critical point in the purification of sewage by e into water. Up to a certain point the organic matter is

successfully nitrified. As soon, however, as the material to be oxi dized exceeds the available oxygen, aerobic purification stops an putrefaction takes its place. Rideal has attempted to express th relation between the various factors involved in the form of an equa tion, $XO = C(M - N)S$, where X = flow of a stream, O = parts of di solved oxygen in the water of the stream per unit flow; S = volume sewage or effluent; M = parts of oxygen consumed by a unit volum of sewage; N = parts of available oxygen in the form of nitrites an nitrates, and C = a constant. When the available oxygen excee the demand all goes well; when it does not, trouble ensues.

The ocean furnishes seaboard cities with the most favorable poss ble conditions for disposal in water. At New York and many oth places small sewers discharge at frequent intervals into tide wate In Boston this method caused a serious nuisance, and as a result somewhat more elaborate system was begun in 1876. Since 18 two main sewers have discharged into the harbor, serving the ci and surrounding metropolitan district, which includes 25 cities a towns with a territory of nearly 200 square miles. The sewage of t region north of the Charles flows continuously from an outlet ne Deer Island Light and amounts to about 50 million gallons per da The sewage from the region south of the Charles, averaging in 19 100 million gallons per day, has been discharged since 1884 at Mo Island, nearer the center of the harbor. Here, in order to protect t adjacent shores, it has been thought necessary to hold the sewage four masonry basins and to discharge it only on the outgoing tid September 19, 1904, a third outlet was opened to take the sewa from certain high-level regions in the south metropolitan distri This discharges continuously in the outer harbor near Nut Island a delivers 20 million gallons per day, leaving the diminished flow Moon Island about 80 million gallons. Experience has shown th no serious nuisance is caused by the Deer Island and Moon Isla outlets. The sewage in the first case disappears within 1¼ miles of t outlet, while off Moon Island the sewage stream may be traced o ward round the south end of Long Island for perhaps 2 miles. both cases passing boats find the immediate vicinity of the out unpleasant, and near Moon Island the value of property on the ma land is said to be affected. No serious menace to health, however involved. The sewage apparently produces no permanent damag the harbor, and recent investigations carried out by J. H. McMa and A. W. Walker in the laboratories of the Massachusetts Instit of Technology indicate that even in high winds there is no tende for sewage bacteria to be carried into the air and blown shorewa So popular is the method of disposal in the sea that according t review made by the Massachusetts State board of health in 1

(Massachusetts, 1903) nearly one-half the population of that State is tributary to such systems. In general they have proved successful, although a serious nuisance is created in some places, as at Lynn, where the sewage is discharged in shallow water and over tidal flats. In any case it is certain that such methods of disposal will prove less and less satisfactory from year to year as the volume of sewage and the concentration of shore population increase. The presence of shellfish beds in locations affected by the discharge of sewage into tide water is a special problem of a serious nature in some localities. It has been exhaustively treated by Fuller (1905 b). The royal sewage commission, in an extensive report on the shellfish question in 1904 (R. S. C., 1904 c), concluded that this evil is a grave one, but that it must be met less by restricting sewage disposal than by regulating the taking and storing of shellfish.

The discharge of sewage into inland waters is less likely to be successful than disposal in the sea. The gravest dangers with large lakes and rivers have arisen from their simultaneous use for sewage disposal and water supply, as in the case of Chicago before the opening of the drainage canal, and to some extent since. In such a case the water supply should always be subjected to its own process of purification; yet where water for drinking is to be taken below the sewage outlet some treatment of the sewage before it discharges furnishes an additional safeguard that is eminently desirable. With smaller bodies of water the increasing proportions of sewage sooner or later exceed the purifying capacity of the stream or pond, and once this point is passed conditions rapidly become intolerable. Just such a condition existed in the Thames, England, prior to the treatment of the sewage of London by chemical precipitation in 1890. In a night trip down the river during one of the investigations of the metropolitan sewage commission of 1882 three of the five members of the commission and their clerk were nauseated by the odor. Gross nuisances of this sort have been created in many streams, both in this country and in England. Blackstone and Neponset rivers, in Massachusetts; Naugatuck River, in Connecticut, below Waterbury; Passaic River between Paterson and Newark, in New Jersey, and Chicago River before the opening of the drainage canal are notorious examples.

By the examination of various rivers it has been possible to fix fairly well the practical limits within which a stream can purify sewage with success. Stearns (1890) estimated that a stream flow of 7 second-feet could safely carry the sewage of 1,000 persons, while if the flow were reduced to 2.5 second-feet a nuisance would result. Hering (1888) set the lower limit at 2.5 to 3.3 second-feet. Goodnough (1903), after a careful study of various Massachusetts streams in connection with the proposed Charles River dam, placed the certain

danger line at 3.5 second-feet per 1,000 persons and found that with 6 second-feet trouble rarely follows. Johnson (1905) converted these figures into dilution volumes as follows:

TABLE IV.—*Proportions of sewage which can be discharged into a stream with safety (Johnson, 1905).*

Authority.	Nuisance probable.	Nuisance improbable.
Hering	1 in 16	1 in 6
Goodnough	1 in 23	1 in 8

Roughly, then, it may be said that a stream will purify one-fiftieth of its volume of sewage, but not much more. In summer, when the volume of diluting flow is least, the high temperature accelerates bac-

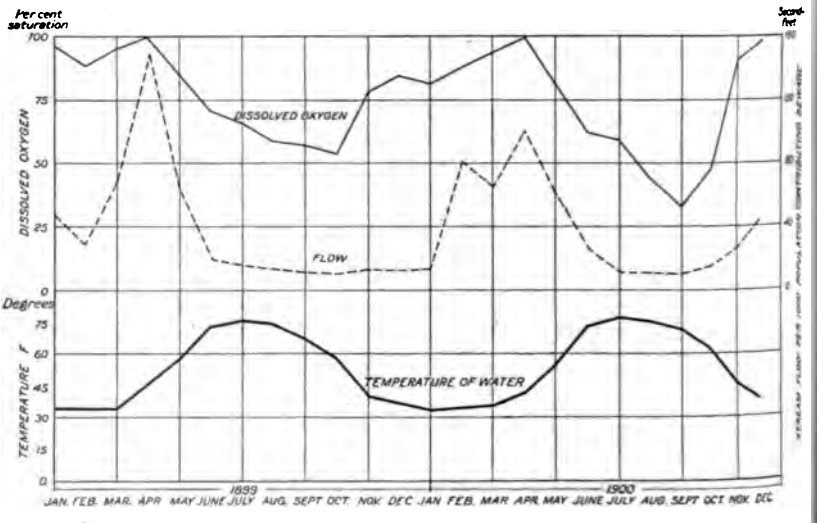


FIG. 3.—Seasonal variations in the condition of Merrimac River at Lawrence, Mass.

terial action and makes an abundant supply of oxygen specially necessary. Table V shows for Merrimac River, above Lawrence, the monthly ratios of stream flow to the sewage-contributing population, estimated at 185,000, together with the mean monthly temperatures and the dissolved oxygen in the river water. The data are graphically shown in fig. 3 and bring out clearly the much greater demand on the purifying power of the river during the summer months. The curve for November and December, 1899, is worthy of special notice, since with no increase in dilution a fall in temperature, with its consequent slackening of fermentation processes, shows a marked rise in dissolved oxygen. Although at the lowest points the dilution does not fall below Goodnough's minimum of 6 second-feet and although the dissolved oxygen averages do not show complete exhaustion, the river

is sometimes distinctly offensive during the summer. Theoretically, while any dissolved oxygen remains there should not be putrefaction; practically, any value below 50 per cent of saturation is likely to be accompanied at times by malodorous conditions.

The data in the following table are taken from annual reports of the Massachusetts State board of health (Massachusetts, 1900 and 1901) and from Water-Supply and Irrigation Papers Nos. 35 and 47 of the United States Geological Survey (1900 and 1901):

TABLE V.—*Seasonal conditions in Merrimac River at Lawrence, Mass.*

Month.	1899.			1900.		
	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).
January	42.6	34	96.3	18.2	33	81.6
February	26.4	34	88.1	89.1	34	87.8
March	64.5	34	95.6	87.7	35	.....
April	143.2	.....	99.3	100	41	99.1
May	51.6	58	84.4	54.1	54	.....
June	16.1	73	71.1	21.4	73	62.1
July	13.4	76	66.6	9.8	77	59.4
August	11.3	74	58.3	10.1	75	43.6
September	10.8	67	57.2	8.2	71	32.5
October	9.7	58	53.7	13.6	62	47.6
November	15.1	40	78.1	31.6	46	91.2
December	15.1	36	84.3	36.6	38	98
Average	34.5	53	77.8	39.9	53	70.3

It is evident that for inland cities, except those situated on the largest lakes and rivers, some other process of sewage disposal must be substituted for the direct discharge into water. In England this s an old story. The first of the royal commissions on sewage disposal nvestigated the subject in 1857 and reported in 1865 that the only way to prevent the pollution of rivers was to purify town sewage by lisposal on land. A second royal commission on rivers pollution, ppointed in 1865, made five exhaustive reports between that date nd 1874, and a third commission, on the metropolitan district, eported in 1884 that treatment of London sewage was essential to the rotection of the Thames. In the United States the Massachusetts egislature in 1872 directed the State board of health to investigate nd report on "the disposition of the sewage of towns and cities," liciting a memorable series of reports from William Ripley Nichols nd his associates, and in 1886 the Lawrence experiment station was ounded for the study of sewage-disposal problems. To-day 23 cities n the State of Massachusetts alone maintain purification works. According to Fuller (1905), about 28,000,000 persons in the United States are connected with sewerage systems. The sewage from 20,400,000 is discharged into fresh water and from 6,500,000 into the sea, leaving 1,100,000 connected with sewage-purification works.

DISPOSAL OF SEWAGES BY BROAD IRRIGATION OR SEWAGE FARMING.

The most obvious alternative to the discharge of sewage into water is its distribution over the surface of suitable land, allowing the liquid to pass through to join the great reservoirs of ground water below. When the amount of sewage on a given area is not excessive the organic solids do not accumulate, but are gradually decomposed with the formation of soluble products beneficial to the growth of the higher plants. The disposal of waste water in every dooryard early gave an illustration of this process, and the absorption of manure in the fertilization of land indicated the great power of the purifying agents involved.

The practice of sewage disposal by broad irrigation gained a firm empirical basis long before there was any comprehension of the true principles involved. At Bunzlau, Prussia, for example, in the sixteenth century, the water from a famous spring was delivered to the inhabitants and a primitive sewer installed. The sewage from the outfall was distributed for irrigation on privately owned farms as early as 1559 with marked success (Du Marès, 1883). At the Craigentinny meadows part of the sewage of Edinburgh has been treated by irrigation for over two hundred years. The development of this method in England was largely due to the health of towns commission of 1844 and the sewage of towns commission of 1857. The latter commission in 1858 gave a full description of the system at Milan, where the liquid refuse of the city was conducted by a canal called the "Vettabbia" to an irrigation area of about 4,000 acres. The same commission concluded in 1865 that "the right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

With the desire to dispose of polluting material grew up a still greater interest in sewage farming as a profitable method of turning organic wastes into valuable crops, Liebig and his followers having laid great stress on the danger of an exhaustion in the nitrogen supply. The two conceptions are well combined in the definition of irrigation by the British metropolitan sewage commission of 1884 as "the distribution of sewage over a large surface of ordinary agricultural land, having in view a maximum growth of vegetation (consistent with due purification) for the amount of sewage applied."

Progress along these lines was rapid in England during the sixties, and many of the present sewage farms were then laid out, as Croydon (1861) and Aldershot (1864). On the continent of Europe the first irrigation plant to be successfully operated on a large scale was at Danzig. In 1869 a contract was signed with an English engineer, Alexander Aird, by which the sewage of the city and 1,300 acres of land were ceded to him for a term of thirty-two years, the entire

ıintenance of the sewerage system being in his charge. The opera-
n of this plant had a special interest on account of the severe
nter weather to which it was subjected. At about the same time
ɔ application of sewage to land was begun at Paris by Mille and
ırand-Claye, after much preliminary investigation by Schloesing,
ıntz, and others, of the chemical and biological principles involved.
present a total area of 13,338 acres at Gennevilliers, Acheres,
d two other adjacent places is irrigated with Paris sewage. The
w amounts to 185 million gallons a day, and the standard rate of
ration is 0.012 million (12,000) gallons per acre per day.[a] The
vage, after passage through screen chambers and detritus tanks,
distributed on farms which are mostly owned by private individ-
ls, although the city operates a small area. Part of the land is
ed for pasturage and part for raising peas, artichokes, tomatoes,
d other table vegetables. The sewage farms of Berlin do not date
ite so far back. Operations were first begun at Osdorf in 1876,
ter a long investigation under the leadership of Rudolf Virchow.
ı area at Falkenberg was added in 1879, and two areas at Gross-
eren and Malchow were added in 1882. The farms are to-day the
rgest in the world, the sewage of a population of 1,750,000 being
eated on 22,881 acres of land at a rate of 0.003 million gallons per
re per day. The crops are chiefly timothy and Italian rye grass.
he farms are operated mainly by convict labor under German mili-
ıry discipline (Roechling, 1892).

The English sewage farms are so designed that the sewage is allowed
ɔ run continuously over the surface of the soil in as thin a film as
ɔssible without being specially encouraged to pass downward. As
rule, the sewage is brought to the highest level on the farm and
ence distributed by open carriers following the contours; these in
rn discharge through lateral carriers or ditches. On many farms
ecial areas of porous soil are leveled so that they may be completely
oded, serving for intermittent filtration, which is discussed on
ges 35–42.

To obtain an available area of proper soil is the chief problem in
vage farming. A light soil on a sandy or gravelly subsoil proves
ɔst satisfactory, while peat, chalk, and clay are bad. All three are
ɔ impervious, and the last two are likely to discharge unpurified
vage through cracks and fissures. With unsuitable soils rates of
ration must be low. Rideal (1901) estimates that the sewage from
) persons can be treated on an acre of loamy gravel and that the
mber may rise to 500 under rarely favorable circumstances, while
th stiff clay it falls to 25. The rates commonly in use in England
ry from 0.002 million gallons per acre per day at Leamington and

[a] Throughout this report rates of filtration are expressed in millions of United States gallons per
per day, and *where possible in "net rates,"* i. e., total quantity passed in a given period divided
the number of days in that period.

Wrexham to 0.015 at Cheltenham and Birmingham (Watson, 1903). German figures range from 0.002 at Brunswick to 0.007 at Danzig, and probably average about 0.004 (Bredtschneider and Thumm, 1904).

When an irrigation farm is overdosed it becomes "sewage sick," to use an expressive English term. The surface clogs, pools are formed, putrefaction begins; only a complete rest restores the health of the area. Under such conditions the temptation to discharge unpurified sewage into the nearest stream is very strong. At times of rain, when sewage flow is highest, the crops are least in need of water and may be seriously damaged by it. The aims of sewage purification are too apt under such conditions to be sacrificed to those of agriculture. Thus, at the famous Craigentinny meadows, where profitable crops are obtained from once barren areas of blown sands, we are told that "the great bulk of the foul water merely runs over the surface of the ground and deposits a portion of its suspended matter" (Barwise, 1904). Many of the English farms, on the other hand, have been operated for thirty years with no nuisance and without the accumulation of offensive sludge.

The statistics for eight of the principal English farms have been compiled from the fourth report of the royal sewage commission (R. S C., 1904 a, b) to form Table VI, and they give a fair idea of general practice. The low rates on clayey soil at Leicester, Rugby, and South Norwood will be noticed, as well as the fact that careful screening and settling has in most cases been found a necessary preliminary The analyses, which from their source may be considered representative, indicate that English irrigation effluents are by no means of exceptional quality, although the Nottingham and Cambridge results are excellent. The Aldershot plant appears to be doing fairly well considering the very strong sewage with which it deals, but at Altrincham and other places the purification is much less satisfactory By incubator tests the Nottingham and Cambridge effluents stood very high, and of the samples from Leicester and Aldershot 90 per cent gave no secondary putrefaction. Norwood, Croydon, and Rugby, on the other hand, gave putrescible effluents about one-fourth of the time. On the whole, it seems fair to conclude from a general survey of English conditions that when a sufficient area of porous soil with a low water table is available a well-managed irrigation area may prove a satisfactory method of sewage disposal from the sanitary standpoint.

Farm.	Date of construction.	Average daily flow (million gallons).	Area of filter bed (acres).	Rate (million gallons per acre per day).	Character of soil and subsoil.	Character of sewage.	Method of treatment.	Material.	Total suspended solids.	Nitrogen as— Total organic.	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.	Oxygen consumed in 4 hours at 80° F.	Remarks.
Aldershot camp..	1864	1	120.5	0.008	Sand.....	Purely domestic.	Screening, settling tanks, and land filtration.	Sewage...	366	50.6	78.7	16.2	.....	207.9	Average of 3 sets of 24-hour samples, January, 1902.
								Effluent..	.....	9.4	18.5	2.6	32.1	27.2	Average of 17 samples, 1900-1901.
Altrincham (Cheshire).	1870	.8	35	.023	Peaty soil lying upon sand and gravel.	Domestic.....	Settling tank and land filtration.	Sewage...	720	12.4	22.9	6.2	.....	52.2	Average of 9 samples, 1900-1901.
								Effluent..	.....	2.6	12.3	1.3	.....	17.5	Average of 16 samples, 1900-1901.
Beddington (Croydon).	1861	4	420	.01	Gravelly loam overlying gravel and sand.	Almost purely domestic.	Screening, surface irrigation, and filtration.	Sewage...	345	20.7	45	9.1	.....	124.8	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	2.61	14.8	1.4	3.7	14.1	Average of 18 samples, 1900-1901.
Cambridge.....	1895	2.25	74	.3	Sandy loam overlying gravel and sand.	Mainly domestic; some brewery refuse.	Screening, settling tank, and land filtration.	Sewage...	265	18.8	38.2	9.1	.....	10.8	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	2.1	6.5	.9	12.6	8.1	Average of 18 samples, 1900-1901.
Leicester.....	1891	7.25	1,350	.005	Stiff clayey soil overlying dense clay.	Three-fourths domestic; one-fourth trade refuse.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	341	23.4	81.2	11.9	.....	223.5	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	4.5	16.5	2	5.1	25	Average of 13 samples' 1900-1901.
Nottingham, ...	1880	7	651	.011	Light sandy loam and gravel overlying gravel and sand.	Four-sevenths domestic; three-sevenths trade refuse.	Screening (partial) and land filtration.	Sewage...	519	31.5	39.8	14.5	.....	232.1	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	.8	1.3	.3	20.6	1.9	Average of 13 samples, 1900-1901.
Rugby.....	1867	.3	35	.009	Heavy loam overlying stiff clay.	Mainly domestic.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	475	32.9	61.1	17.3	.....	184.4	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	1.7	16.2	1.8	5.2	14.1	Average of 19 analyses, 1900-1901.
South Norwood.	1864	.6	152	.004	Clay soil resting on London clay.	Purely domestic.	Screening, settling tanks, and surface irrigation (with a little filtration).	Sewage..	219	14.9	35.4	6.7	.....	77.1	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	10.4	8.7	1	3.9	14.4	Average of 11 analyses, 1900-1901.

The economic advantage of sewage farming is somewhat more doubtful. English chemists estimate the manurial value of sewage at from 1 to 4 cents a ton (Rafter and Baker, 1894). This value can no doubt in part be recovered, since the crops grown on sewage fields are often astonishingly heavy. Whether it really pays to recover it depends on local economic conditions. In many English towns the operation of farms has proved unprofitable, and there is some tendency toward their abandonment. Lieut. Col. A. S. Jones and others are, however, ardent advocates of the process; and in certain cases the farm, besides paying all running expenses, yields in some years as much as $12 an acre toward rent (Baker, 1904). McGowan, Houston, and Kershaw, in their valuable report to the royal sewage commission, conclude:

> Although we are of opinion that sewage farms in general can never be expected to show a profit if interest on capital expenditure is included, the fact that in favorable seasons some of them more than cover the working expenses is a point in favor of cropping in connection with the land treatment of sewage. [R. S. C., 1904 c.]

With regard to the question of the sanitary quality of the produce grown on a sewage field, the experience of Berlin and Paris indicates that there need be no serious danger of the spread of disease from irrigated crops. The writers believe, however, that fruits and vegetables to be eaten raw should never be so treated; and McGowan, Houston, and Kershaw (R. S. C., 1904 c) would limit sewage farms to stock raising, saying:

> We are, on the whole, not in favor of sewage farms being utilized for the raising of crops for human consumption.

In the western part of the United States the conditions for sewage farming are specially favorable. In the arid regions some form of irrigation is essential and the manurial value of sewage is reenforced by its water value. The first plant in this country was laid out at Cheyenne, Wyo., in 1883, and to-day there are a score or more of sewage farms in operation, of which those at Los Angeles and Salt Lake City are the largest. The experience of Los Angeles is of considerable interest as indicating the value of sewage in such a region. Prior to 1889 the sewage from the city, amounting to 7 million gallons, was carried to the so-called Vernon district, where it was taken by the South Side Irrigation Company and distributed to adjacent farms. So useful did the sewage prove that the value of the land rose from $2.50 an acre to from $15 to $25. A boom followed, house lots were developed, and the population so increased that the sewage, which had built up the district, became a nuisance and had to be taken elsewhere.

In the East the problem of sewage irrigation takes on a different aspect. The high cost and poor quality of land and the heavy rains of spring and autumn combine to make the success of such a venture

ɔre than problematical. It is true that the waste of valuable ınurial elements is unfortunate, and authorities like Rafter (1897) ve been strongly moved by such considerations. The saving of ganic nitrogen, however, appears to-day in a less important light ın formerly, since we know that its dissipation may be made good ım the ocean of the atmosphere by the activities of the nitrogen-ing bacteria. At any rate the question is one which must be judged a basis of dollars and cents. There are valuable elements in sewage, there is gold in sea water; but if it costs more to save them than ɔy are worth after they are saved we must let them go. On the cific coast sewage farming is profitable. In the East, under present ıditions, it is unlikely to prove so.

TREATMENT OF SEWAGES BY CHEMICAL PRECIPITATION.

Parallel with the development of broad irrigation there grew up a ɔthod, or a group of methods, for the utilization of the useful ele-ɜnts in sewage on a different principle. The idea that sewage sludge ɜy be valuable is so discredited to-day that it is difficult to believe at the first attempts at chemical treatment were made with a view the recovery of its constituents in a "portable and consequently arketable form." Such, however, was the object with which numer-ɜs processes were devised in the early sixties. Between 1856 and 76 no less than 417 patents were issued in England for processes nnected with the chemical precipitation of sewage.

The various methods of treatment consist, as a rule, of two stages—e addition of some substance which will produce a flocculent pre-ɔitate, and the sedimentation of the mixture to separate the heavy ıdge from the supernatant liquid. The precipitants used are vari-s, but the active elements in most cases are salts of lime, aluminum, iron. The rivers pollution commission in its report of 1870 dis-ssed the action of lime, lime and chloride of iron, sulphate of alumi-m, Sillar's "ABC" mixture (alum, blood, and clay with other sub-ınces), and Holden's compound (iron sulphate, lime, and coal dust). ızen (1890) in 1889 carried out for the Massachusetts State board health an elaborate series of experiments, from which it appeared ıt either ferric salts or a mixture of ferrous sulphate with lime ɔved most satisfactory. In the first case ferric hydroxide was pre-ɔitated, and in the second case ferrous hydroxide, calcium carbon-ɜ, and various insoluble organic lime salts. Ferrous sulphate alone ve less satisfactory results, as did also sulphate of aluminum.

Exhaustive studies of various precipitants were made by Dibdin connection with the treatment of the sewage of London, results and ɜt of different processes being worked out in great detail. All sus-nded matter could be removed, and with regard to the dissolved ganic matter the efficiency ranged from a removal of 10 per cent

with 52 parts per million of lime to a removal of 31 per cent with 784 parts of lime, 168 parts of ferrous sulphate, and 560 parts of sulphate of aluminum, and a removal of 52 per cent with 9,800 parts of lime, 1,400 parts of ferrous sulphate, and 700 parts of sulphate of aluminum. The annual cost for a daily flow of 157 million gallons was estimated at $60,000 for the first result quoted, $400,000 for the second, and nearly $50,000,000 for the third. In general it was found that lime was the best basis, and for use in combination with it iron salts were preferable to those of aluminum. The combination finally determined on was 56 parts of calcium oxide (4 grains per gallon) with 14 parts of ferrous sulphate (1 grain per gallon). After the addition of precipitants the sewage is allowed to settle in tanks where it either remains quiescent for a time or flows through slowly and continuously. The second or continuous method is most satisfactory, and a capacity of from one-half to twice the daily flow is sufficient for sedimentation. For a complete separation on a small area a tank of special form is sometimes used, whose bottom is an inverted cone in which the sewage passes upward, its flow supplementing the action of gravity. At a certain level in the tank the precipitated material collects, so as to form a sort of filtering layer through which the ascending sewage must pass. A tank of this form (Röckner-Rothe type) was installed at the World's Columbian Exposition in Chicago in 1893 (Hazen, 1894); it was practically identical with the Dortmund tank extensively used in German plants for the treatment of industrial wastes.

The results to be expected from the chemical treatment of sewage may be learned from the experience of London. The sewage of the city was originally discharged from the various sewers directly into the Thames, producing a nuisance which culminated in the historic stink of 1858. To cope with these conditions a system of intercepting sewers was completed in 1865 which discharged the sewage from the district north of the river at Barking Creek and that from the south side at Crossness, about 12 miles below London Bridge. This arrangement proved satisfactory for a time, until the volume of sewage had too greatly increased. By 1875, however, it became necessary to discharge part of the flow on the flood tide; the liquid carried up the river and the solids deposited on the shores became once more a serious nuisance. In 1882 the metropolitan sewage commission was appointed and advised the removal of solid matter from the sewage by deposition or precipitation. In accordance with its recommendations precipitation works were constructed at both outfalls, the sewage being treated, as noted above, with 56 parts per million of calcium oxide and 14 parts per million of ferrous sulphate. At the present time the same system is still in force. The sewage from the city of 4,500,000 inhabitants amounts to 280 million gallons per day

d 7,200 long tons of sludge are daily carried 50 miles out to sea by fleet of six dumping boats. The total cost of treatment is nearly 00,000 a year (Baker, 1904). The results of the chemical treatment · London are indicated in Table VII and show a removal of some-ıat over three-fourths of the suspended matter, but only slight provement in the soluble constituents. The effluent is by no means rified. It is merely so improved by the removal of most of its ids that its discharge into the Thames is for the time being per-ssible.

TABLE VII.—*Results of chemical precipitation at London, 1894 (Dibdin, 1903).*

[Parts per million.]

Source.	Material.	Suspended solids.	Dissolved material.			
			Total.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—	
					Free ammonia.	Albuminoid ammonia.
thern outfall	Sewage	417	862	44.5	35.6	4.1
	Effluent	99	910	46.2	36.9	4.2
thern outfall	Sewage	441	1,300	53.1	34.8	4.9
	Effluent	87	1,420	44.5	28.9	3.9

At Manchester conditions appeared somewhat more favorable for cipitation on account of the presence of certain chemicals in the tory wastes, and only 31 parts of calcium oxide and 17 parts of rous sulphate were added. The results with respect to the total ganic constituents are indicated in Table VIII. The figures are e-year averages of the results of analyses made twice a day on urly samples. The purification of the effluent proved inadequate meet local conditions, and the system has been abandoned in favor newer biological processes.

BLE VIII.—*Results of chemical precipitation at Manchester, England, 1900–1904 (Manchester, 1900–1904).*

[Parts per million.]

Material.	Oxygen consumed in 4 hours.	Oxygen consumed in 3 minutes.	Nitrogen as—	
			Free ammonia.	Albuminoid ammonia.
age	116	56.7	23.6	5.9
k effluent	76.4	37.2	24.2	3.9

At Birmingham a number of chemical processes were tested in '1 and found unsatisfactory. Watson, the present engineer of the ıinage board, comments:

venture to say that a similar conclusion would have been arrived at if the committee, ead of trying only seven chemical processes, had tried all the 454 processes which were ›nted *previous to 1886.* [Watson, 1903.]

At Salford a thorough test of 13 different precipitants yielded no satisfactory effluents.

The disposal of the sludge is a serious problem in chemical precipitation. Its quantity is considerable, amounting to 26 tons per million gallons of sewage at Salford, 21 tons per million gallons at Manchester, and 60 tons per million gallons at Chorley. Of this crude sludge 90 to 95 per cent is water. Wallace found the composition of the air-dried residue from eight different English plants to average 12 per cent of water, 26 per cent of organic matter, 1 per cent each of nitrogen and phosphoric acid, and 35 per cent of sand (Robinson, 1896). Far from being marketable, as the projectors of the process dreamed, the disposal of this sludge generally involves considerable expense. In 1894 a canvass by the local government board showed that of 234 places using chemical processes only 30 were able to obtain any revenue from sludge. In some German plants the sludge is evaporated and burned for generating gas. The usual course, however, is to compact it in filter presses and dispose of the press cake by burning it or burying it in the ground.

On the whole, chemical precipitation has become somewhat discredited of recent years. The cost of chemicals is considerable, the disposal of the sludge is vexatious, and the effluent produced is imperfectly purified and always subject to secondary putrefaction. Except under special conditions this treatment can be considered only a preliminary process, to be followed by some final biological treatment which shall effect real purification. Even in this rôle the process is generally less applicable than the septic tank, since, as compared with the latter, it produces results only slightly better with a considerable additional cost for chemicals and with an increase in the quantity of sludge.

In special cases, however, chemical treatment still has its application. While most English cities are abandoning chemical precipitation for some newer process, Glasgow is installing new tanks which will eventually handle 140 million gallons of sewage daily, using lime and sulphate of alumina as precipitants. The experience of Worcester, Mass., is of considerable interest in this connection, since there, too, chemical precipitation is apparently likely to be maintained. In 1867 the city of Worcester was permitted to use as a common sewer Mill Brook, which discharges into Blackstone River. In 1880 vigorous complaints began from Millbury and other towns below that the stream was so foul as to be a nuisance and a danger to the health of the community. Phineas Ball, Colonel Waring, and others reported various plans for relief, and in 1882 the State board of health recommended the installation of intermittent filters. In 1884 the legislature ordered that the city should remove from its sewage before discharge into Blackstone River "the offensive and polluting

rties and substances therein, so that after its discharge into said it shall not create a nuisance which might endanger the public ı." A chemical precipitation plant was duly installed in 1890, he condition of the river remained bad. In 1895 Millbury ht suit against Worcester on the ground that the act of 1886 had een complied with. After full expert discussion it appeared he condition of the river was in part due to the past pollution . had for years accumulated in its bed as sewage mud, and in to the imperfectly purified chemical effluent still being dis- ed. The courts declared that the city had acted in good faith empting to carry out the act of 1886, but ordered that it should further steps to comply with its provisions. Since that date areas for intermittent filtration have been progressively added ıe final purification of the chemical effluent. It is possible in ase that chemical treatment is the best available preliminary ss, since the city sewage contains free sulphuric acid and sul- of iron from the wire works which aid the chemical process erhaps interfere with bacterial action.

1904, 4,622 million gallons of sewage were received at the Worces- orks, of which 4,227 million gallons were treated chemically. undred million gallons of the chemical effluent and 395 million ıs of raw sewage were treated on sand filters. Lime is the only ›itant used, in the amount of 120 parts per million, sufficient ›eing already present in the sewage to complete the reaction. very million gallons of sewage treated 5,756 gallons of wet sludge ›tained, containing 6.93 per cent of solids. After pressing, this uced to 5.7 tons of pressed sludge containing 28.9 per cent of . The cost of pressing and sludge disposal amounts to over r million gallons. The analyses of sewage and effluent from to 1904 show that the yearly removal of the total albuminoid ›nia has varied from 46 to 63, averaging 52 per cent; of total ›n consumed from 37 to 59, averaging 51 per cent; of suspended ıinoid ammonia from 83 to 98, averaging 93 per cent; and of nded oxygen consumed from 77 to 89, averaging 82 per cent ›ester, 1905). The results for 1904 are shown in Table IX.

IX.—*Results of chemical precipitation at Worcester, Mass., 1904 (Worcester, 1905).*

[Parts per million.]

Material.	Nitrogen as—			Oxygen consumed in 2 minutes' boiling.	
	Free ammonia.	Albuminoid ammonia.			
		Total.	Soluble.	Total.	Soluble.
vage	15.9	6.8	2.5	96.9	59.7
l effluent	14.4	3.4	3.1	54.2	43.1

Another large American precipitation plant is that at Providence, R. I., where since the sewage effluent is discharged into a tidal estuary the removal of suspended solids alone is all that is necessary. Precipitation was recommended by S. M. Gray after an exhaustive investigation in 1884, but the plant was not finally installed until 1902. Comparative statistics for the operation of the Worcester and Providence purification works in 1903, copied from Fuller, are given in Table X.

TABLE X.—*Statistics of chemical precipitation at Worcester, Mass., and Providence, R. I., 1903 (Fuller, 1905 a).*

	Worcester.	Providence.[a]
Population connected to sewers, estimated	122,000	170,000
Average daily sewage flow, total ... million gallons	15.55	20.30
Average daily sewage flow, treated ... do	14.39	20
Total annual sewage flow treated ... do	5,250	7,300
Applied lime ... pounds per million gallons	871	606
Applied lime ... grains per gallon	6.1	4.2
Applied copperas ... pounds per million gallons	0	65
Applied copperas ... grains per gallon	0	.46
Gross capacity of basins ... million gallons	5.5	11.1
Percentage of removal:		
Total organic matter by albuminoid ammonia	51.69	a 40.80
Suspended organic matter by albuminoid ammonia	91.58	a 82.54
Wet sludge:		
Average pressed daily ... gallons	67,200	95,600
Percentage of total sewage flow	.4671	.4776
Average percentage of dry solid contents	7.44	5.37
Average amount of lime added per 1,000 gallons ... pounds	33.5	23.6
Pressed sludge cake ... tons daily	69	76
Pressed sludge cake ... percentage of dry solids	30.3	28.25
Dry solids in sludge:		
Tons daily	20.80	21.40
Tons per million gallons	1.45	1.07
Tons per 1,000 population per annum	62	46
Cost of sludge pressing and disposal:		
Per ton of dry solids	$3.89	$2.27
Per million gallons sewage flow	$4.91	$2.44
Cost of chemical precipitation (labor and supplies) per million gallons	$4.01	$3.31
Total cost of operation:		
Per million gallons	$8.92	$5.75
Per capita connected to sewers per annum	$0.384	$0.248
Cost per ton:		
Lime	$6.00	$6.90
Copperas		$7.80
Minimum wage per hour for laborers	$0.23½	$0.15

[a] Providence sewage well screened before treatment.

Before leaving the subject of chemical treatment it will be well to refer briefly to certain special processes which have been suggested and adopted in exceptional cases without finding general application. For example, with the Liernur system of sewerage in use in certain Dutch and Belgian cities, which lie at too low a level for gravity systems, the excreta diluted with a small volume of water are drawn off by suction through a system of tight sewers, and sewage of this type has been handled by direct evaporation, the residue being used as fertilizer. Its application is naturally limited (U. S. Dept. State, 1895). The Degener process applied in some German cities involves mixture of the sewage with crushed lignite, precipitation with ferric sulphate, pressing of the sludge, and treatment of the effluent with bleaching powder. The process is costly, but at Potsdam and Tegel is said to

›duce a very perfect effluent (Grünbaum, 1902). The bleaching wder in this process is supposed to disinfect the final effluent; and ; same end is aimed at in a number of chemical processes based on ; use of such substances as ozone and the oxychlorides. The ›bster process allowed sewage to flow between iron electrodes so ıt the chlorides present were electrolyzed, liberating free chlorine l oxygen and forming iron salts. In the Hermite process a ›nger action was obtained by electrolyzing sea water and adding it the sewage (Rideal,1901). Considerable interest has been mani-ed in these and similar methods during the last year. Disinfection cesses, however, ignore the fundamental problem of sewage dis-al, which is the production of an oxidized, not of a sterile, effluent. til a really purified and stable effluent has been produced disin-;ion is a step in the wrong direction.

ın interesting method has been suggested by Adeney and installed Kaye Parry at Dundrum, Chapel-Izod, and other Irish towns. It ıs at the addition of chemicals in such a way as to favor rather than ;heck biological action. The sewage is first precipitated by oxanite, ich is a crude sulphate of manganese mixed with the higher oxides ;hat element, and then nitrate of soda is added to the supernatant ıid. The manganese supplies the sludge with oxygen, so that a ›id aerobic fermentation occurs and the nitrate performs the same ıction for the effluent.

RIFICATION OF SEWAGES BY INTERMITTENT FILTRATION THROUGH SAND.

The only general method for the purification of sewage is its oxida-n by micro-organisms. We have seen how this process has been ıpirically utilized in dilution and in broad irrigation. Its scientific nciples were grasped by a few investigators at an early date. ›out 1865 Alexander Mueller described the purification of sewage as ›rocess of digestion and mineralization carried out by minute animal l vegetable organisms (Rideal, 1901). In 1878 he took out a patent a "process for the disinfection, purification, and utilization of ›age by the scientific cultivation of yeastlike organisms" (Bruch, 9). In 1877 the fact that the purification of sewage is due to ;teria was demonstrated by Schloesing and Muntz in a series of ›eriments in which it was shown that nitrification did not occur in s sterilized by heat or chloroform (Schloesing and Muntz, 1877). ›rington reported further suggestive results along this line in 1892. These suggestions appear to have made little impression in Great tain and the United States. Meanwhile, however, the practical e of the subject was undergoing an important development in gland. In 1870 Sir Edward Frankland carried out a series of nificant experiments, the results of which were published in the

first report of the rivers pollution commission. Sewage was filtered both upward and downward through various soils at different rates, and it was shown that a good effluent could be obtained by downward filtration through coarse gravel at a rate of 0.08 million gallons per acre per day, while upward filtration produced only a foul and turbid effluent. Doubling the rate interfered with the purification, and it was seen that a resting or aerating period between the applications of sewage was a necessity. The principle of the process as a chemical oxidation of organic matter to water, carbon dioxide, and nitrates was clearly recognized, as well as the practical necessity for intermittency in operation. The cycles in the life of a sewage filter were compared to the inspirations and expirations of the lungs (rivers pollution commission, 1870).

These researches indicated that with suitable soil the process of broad irrigation might be made more intensive, the growing of crops being subordinated to the treatment of sewage at a more rapid rate. This principle was quickly applied on a practical scale by J. Bailey-Denton, who constructed an intermittent filter at Merthyr Tydvil, Wales, in 1871. Beds 20 acres in area were furrowed, cropped, and operated at a rate of 0.06 million gallons per acre per day. This rate was later reduced to 0.016 by the addition of more irrigation land, but the original plant worked admirably and was of importance as a practical demonstration of Frankland's experiments on a large scale (Bailey-Denton, 1882). Neither Frankland nor Bailey-Denton, however, understood the biological nature of the process. The latter said of his filters in 1882:

> The assimilative powers of growing plants are brought to bear on the fertilizing elements of the sewage at the same time that the percolation of the sewage through the soil brings it in contact with the atmospheric air pervading the soil and renders it harmless by oxidation, as explained by the rivers pollution commissioners.

Altogether, it is clear that in the early eighties the *theory* of sewage oxidation was understood by French and German investigators. On the other hand, the *practice* of intermittent filtration had been empirically worked out in England by Frankland and Bailey-Denton. The laboratory investigations, however, were academic and the practical data incomplete. To combine a sound conception of the biological principles involved with a study of the engineering data of operation on a practical scale was left for American investigators. English sanitarians have not been slow to recognize that "it was primarily due to the Massachusetts State board of health, who began their investigations in November, 1887, and have continued them ever since, that the bacterial treatment of sewage has been forced on public attention" (Watson, 1903). For the mass of data accumulated and the thoroughness with which these data were analyzed, as well as for the almost revolutionary effect which they

orked in sewage practice, the Massachusetts experiments well serve the term of "classic," by which they are so commonly signated.

In 1886 the legislature of Massachusetts charged the State board health with the advice of cities and towns, corporations, and lividuals as to water supply and sewage disposal and ordered it collect information and conduct experiments on the purification sewage. Hiram F. Mills, a distinguished hydraulic engineer and a mber of the board, organized the investigation, with the assist-e of T. M. Drown and W. T. Sedgwick, both of the Massachu-ts Institute of Technology, as chemist and biologist, respectively. experiment station was fitted up in 1887 on the bank of Merri-c River at Lawrence, under the immediate charge of Allen Hazen. re ten circular cypress tanks 17 feet in diameter and 6 feet deep e filled with various filtering materials—sand, gravel, peat, river , loam, garden soil, and clay—and dosed with sewage pumped m the city sewer. The results exceeded the hopes of the inves-ators. By passage through a fairly porous soil on the intermit-t plan, one dose being applied every twenty-four hours, sewage ld be converted into a clear and completely nitrified effluent. at and garden soil proved too impervious and, although operated very slow rates, clogged. In this condition the air supply was t off and nitrification failed. All the other filters showed good rification at rates of from 0.02 to 0.1, the quality of the effluents ing equal in many cases to that of well waters in use in the city Lawrence.

The true nature of sewage purification as a bacterial oxidation s clearly brought out in these experiments. Intermittency of plication supplies the needed oxygen, and any fairly porous mate-l will serve as a resting place for the active bacteria.

he experiments with gravelstones give us the best illustration of the essential char-er of intermittent filtration of sewage. In these, without straining the sewage suffi-ntly to remove even the coarser suspended particles, the slow movement of the liquid thin films over the surface of the stones, with air in contact, caused to be removed some months 97 per cent of the organic nitrogenous matter, a large part of which in solution, as well as 99 per cent of the bacteria, which were of course in suspen-, and enabled these organic matters to be oxidized or burned, so that there remained the effluent but 3 per cent of the decomposable organic matter of the sewage, the ainder being converted into harmless mineral matter.

he mechanical separation of any part of the sewage by straining through sand is an incident, which, under some conditions, favorably modifies the result; but the ntial conditions are very slow motion of very thin films of liquid over the surface of ticles having spaces between them sufficient to allow air to be continually in contact h the films of liquid.

Vith these conditions it is essential that certain bacteria should be present to aid in process of nitrification. These, we have found, come in the sewage at all times of year, and the conditions just mentioned appear to be most favorable for their efficient ion and at the same time most destructive to them and to all kinds of bacteria that in sewage. *[Mills, 1890.]*

The organisms active in the nitrifying process, isolated independently by Winogradsky in France and by Richards and Jordan (1890) at Lawrence, have been studied by a number of bacteriologists, of whom Schultz-Schultzenstein (1903) and Boullanger and Massol (1903) are perhaps the latest. The necessity for an alkaline base for nitrification, known to agriculturists since the time of Varro, has been confirmed by these observers, who find that free acids, organic or inorganic (0.5 per cent), and nitrates or nitrites in 1 to 3 per cent solution, quickly check the work of the organisms. A marked excess of free ammonia or of any alkali has the same effect. Thus Warington found that a 12 per cent solution of urine having a maximum alkalinity of 446 parts of ammonia as carbonate would stop nitrification. At Burton sewage containing 100 parts of free lime would not nitrify till it was neutralized (Barwise, 1904). Rideal also notes a harmful effect due to carbon dioxide, and Letts believes that sodium chloride from sea water hinders the formation of nitrates at Belfast (R. S. C., 1902 a). The optimum temperature for the reaction lies between 28° and 37° C. It is stopped in the neighborhood of 50° C.

Later work at Lawrence, where numerous small experimental filters have been operated since 1890, has brought out further details of the process of intermittent filtration. In the 1891 report, prepared by Allen Hazen, the chemist in charge of the station, it was shown that while most of the organic matter of the sewage is actually destroyed and while there is no important storage in the depths of the filter, its surface accumulates a certain amount of stable organic matter which must be removed at intervals. It was made apparent that in severe winter weather the quality of the effluent, while considerably deteriorated, was still reasonably satisfactory. The maximum rate at which sewage could be conveniently applied varied from 0.03 with sand of an effective size of 0.03 mm. to 0.06 with sands of 0.06 to 0.35 mm., 0.1 with sands of 0.17 and 0.48 mm., and 0.2 with gravel of 5 mm.

One of the strong points about the Lawrence experiments has been their continuity for a sufficient period to show the long life of intermittent filters, four of the original outdoor filters having been operated for seventeen years. A comparison of the effluents during the first seven and the last nine years of operation has been compiled from the reports of the State board and is shown in Table XI. Although, with a considerably increased concentration of sewage the effluents have deteriorated, yet the percentage purification has only slightly decreased, and the effluents are still of good quality.

.I.—*Results of intermittent filtration at Lawrence, Mass., in successive periods (Massachusetts, 1895–1903).*

	Quantity of sewage applied (gallons per acre per day).	Temperature (°F.)	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	Chlorine.
			Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		
-1894								
.1	76,000	53	2.3	0.4	16.8	0.18	4.7	68.5
.2	34,000	52	1.7	.1	15.9	.15	1.7	65.4
.4	27,000	52	1.7	.2	10.4	.02	3.7	59.9
.6	47,000	53	1.9	.3	16.4	.34	3.2	68.1
.9A	74,000	53	4.9	.3	18.3	.08	3.2	80.2
			18.8	5.5			36.2	68.4
-1903.								
.1	51,000	55	8.6	.6	25.8	.23	6.6	94
.2	30,000	54	5.8	.3	28	.10	3.3	91.4
.4	16,000	54	2.4	.2	26.9	.03	1.8	86.1
.6	51,000	54	7.6	.6	26	.31	5.8	90.8
.9A	52,000	54	8.8	.5	26.7	.09	5.6	89.6
			32.6	5.9			41.3	91.8

early Massachusetts experiments led at once to practical devel-
.ts. In the 1887 and 1888 reports of the board of health pre-
ry results were announced, and in 1889 the board reported that
suggested for the disposal of the sewage of the Mystic Valley
Saugus marshes was impracticable on account of the peaty
of the soil. Also in 1889, in accordance with the favorable
obtained at Lawrence by filtration through coarse sand, the
.rge intermittent filtration area in the State was laid out in the
of Framingham. Gardner and Marlboro followed in 1891,
t the same time the first filter in Connecticut was built at
en.

903 (Massachusetts, 1904) the State board of health of Massa-
ts discussed the results of the operation of 23 plants in the Com-
ealth. All made use of intermittent filtration, and the report
des that—

eady availability of sand and gravel areas naturally adapted for the purification
ge, the simplicity of the process, and the small cost of maintenance have made this
of purification the most advantageous for adoption in practically all the cases in
ewage-purification works have been found necessary, and the resulting effluents
nto the stream have been satisfactory in all cases where the works are of sufficient
and have received proper care.

principal analytical data from the report are shown in Table
which gives a fair idea of the operation of the intermittent proc-
It will be noted that the rates vary in general from 0.05 to 0.1
at the effluents are in most cases of satisfactory quality. They
perior in almost every instance to those obtained at the English
e farms, as shown in Table VIII.

TABLE XII.—*Statistics of intermittent filtration in Massachusetts (Massachusetts, 1904; Worcester, 1905).*

Place.	Date of construction.	Average daily flow (million gallons).	Area of filter beds (acres).	Rate (million gallons per acre per day).	Population contributing sewage.	Preliminary treatment.	Material.	Average of monthly analyses, 1903[a] (parts per million).				
								Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
								Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	
Andover	1898	0.125	3.65	0.0342	3,600	Screening; sedimentation	Sewage	39.7	5.6			49
							Effluent	9.1	.5	8.3	0.2	7.4
Brockton	1894	.878	21.48	.0409	25,000	Partial sedimentation	Sewage	43.8	12.9			219
							Effluent	1.9	.1	30.8	.1	3.3
Clinton	1899	.785	23.5	.0334	10,000	do	Sewage	33.2	7.9			113.7
							Effluent	.8	.6	4.4	.2	11.2
Concord	1898	.312	3.3	.0945	1,200	Screening	Sewage	5.7	1.4			13.6
							Effluent	.01	.09	8.5	0	1.1
Framingham	1889	.652	19.9	.0328	7,500	do	Sewage	26.1	6.5			47.3
							Effluent	1.8	.2	9.9	.2	2.6
Gardner (Gardner system).	1891	.302	2.5	.1208	3,500	Sedimentation	Sewage	20.2	4.9			49.2
							Effluent	14.8	.7	.4	0	10.7
Hopedale	1892	.150	2.3	.0652	2,000	Septic tank	Sewage	18.3	2.8			29.8
							Effluent	8.6	.7	15.9	.3	7.2
Leicester	1894	.030	.36	.0833	500	Sedimentation	Sewage	22	4.1			50.8
							Effluent	5.8	.7	9.1	.4	9.6
Marlboro	1890	1.100	11.2	.0982	10,000	do	Sewage	25.9	4.4			44.4
							Effluent	10.2	.5	3.5	.3	7.3
Natick	1895	.566	11.1	.0510	4,000	Screening	Sewage	12.2	2.6			32.7
							Effluent	5.1	.3	2.2	.2	4.4
Pittsfield	1890	1.456	21.67	.0672	15,000	do	Sewage	12	8.2			79.2
							Effluent	2.2	.3	6.7	.2	3.8
Southbridge	1899	.350	7.25	.0483	2,200	do	Sewage	16	3.5			40.1
							Effluent	3.2	.3	2	.1	3.6
Spencer	1897	.375	9.3	.0403	3,000	do	Sewage	1.5	4.5			46.5
							Effluent	1.2	.2	3.7	.2	3.3
Stockbridge	1899	.075	3.6	.0208	800	do	Sewage	9.8	1.6			15.2
							Effluent	0.9	.2	1.4	0	3.3
Westboro	1891	.282	4	.0705	3,000	Screening; partial sedimentation	Sewage	13.8	4.4			35.5
							Effluent	5.3	.7	3.6	.5	7.3
Worcester	1898	1.080	8.77	.123	122,000	Sedimentation	Sewage	18	8.1	.6	.1	138.7
							Effluent	10.9	.9	2	.3	18.1

[a] Worcester analyses of daily samples analyzed weekly from December 1, 1903, to December 1, 1904.

h regard to the comparative results of different Massachusetts the following points may be noted: The poor effluents at oro and Gardner are due partly to careless operation, the sew- ing allowed to run on continuously for days. At Clinton the d sewage is very strong. At Leicester, Andover, and Hopedale ard attributes results below the average to the fact that the is stale or septic when applied. At Worcester the sewage is , and it is probable that its acid-iron waste interferes somewhat he process of nitrification. It has been thought best, at any ot to attempt to treat crude sewage, as was done in the experi- included in Table XII. The comparative results of filtration nd without chemical precipitation, as shown in Table XIII, te the great advantage of special treatment.

XIII.—*Results of intermittent filtration of crude sewage and chemical effluent at Worcester, Mass. (Worcester, 1905).*

[Parts per million.]

Material.	Nitrogen as—					Oxygen consumed.	
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.	Total.	Soluble.
		Total.	Dissolved.				
age	18	8.1	3.8	0.6	0.1	138.7	79.5
effluent	10.9	.9	.9	2	.3	18.1	18.1
effluent	20.1	3.6	3.2	1.1	.4	56.5	44.4
effluent	.8	.7	.7	4.1	.2	9.5	9.5

onstruction the Massachusetts filters are simple, being built in l of natural glacial drift. The subsoil is removed, being used n embankments between the beds, and the sand is not dis- except for the laying of underdrains. Beds, as a rule, are 1 area, the sewage being distributed through branched wooden s of sizes so varied as to secure approximately uniform distri- . This point is of much importance, since the passage of large es of sewage through a portion of a bed necessarily leads to results. At many plants, as at Framingham, Natick, and on, crops have been grown on the beds. At Brockton this e has recently been abandoned, since it was found to cause an ulation of fine organic matter detrimental to the surface.

effect of winter weather on the process has not been found to be . The actual freezing of the surface is prevented by furrowing ds, so that a layer of ice forms on the top of the ridges, leaving n space between them. Here the sewage flows, its warmth sufficient to keep the surface open under the covering of ice. ocess of nitrification is, however, considerably interfered with direct action of cold, as is shown on page 131 of this paper. act, combined with the impossibility of scraping off surface

accumulations during severe weather, leads to a general clogging of the filters during the winter months. With ample capacity this period may easily be tided over. Goodnough said in 1904 (Winslow, 1905 b):

> Of the 15 sewage-disposal plants of considerable size where works were originally provided for the treatment of all of the sewage, all of the sewage is treated at all times at 6 places, or more than one-third of those having purification works, and very little sewage is discharged untreated at 6 of the remaining places, leaving only 3 places out of the 15 at which, at the present time, any considerable quantity of sewage is allowed to escape without treatment.

The accumulation of a certain amount of material on the surface of the beds is a necessary feature of the process of intermittent filtration as practiced in Massachusetts. This material, appearing in the form of a dry cake of a stable and inoffensive character, scarcely deserves the name of sludge, by which it is frequently designated. However, it necessitates a considerable expense in operation. The beds must be frequently raked and harrowed and occasionally plowed and scraped. At Pawtucket it has been found in ten years that for every million gallons of sewage 8.39 cubic yards of material (including sand) were removed from the surface (Pawtucket, 1904). At the Brockton plant, which is admirably designed and operated, full data are published on this point. In 1904 a daily flow of 900,000 gallons from a population of 40,000 was treated on 21½ acres of sand. A storage well at the pumping station holds the night flow of sewage, so that the pumps are run only in the daytime. The sediment which collects at the bottom of this reservoir is stirred up at the end of a run and discharged on four special "sludge beds." The cost of labor on the surface of all the beds during 1904 was $2,932, and the total cost of maintaining the area $4,412 (including gate tending, care of roadways, etc.), amounting to over $15 per million gallons (Brockton, 1905). The expense of maintenance at 16 Massachusetts plants varied in 1903 from $0.61 per million gallons at Natick to $21.92 at Stockbridge (Massachusetts, 1904). The Natick beds received practically no care except in connection with cropping, but operated satisfactorily. The next lowest figures were $2.45 at Pittsfield and $2.60 at Marlboro (large plants) and $2.87 at Concord (weak sewage). The costs at Clinton, Southbridge, Spencer, Westboro, and Worcester were between $3.91 and $7.80; at Gardner, over $9 at each of its two areas; at Brockton and Leicester, $11; and at Andover, $13.98.

TREATMENT OF SEWAGES IN THE SEPTIC TANK.

While the process of intermittent filtration was being scientifically developed in Massachusetts, English sanitarians were beginning to treat sewage on a totally different principle—that of anaerobic putrefaction. At an early period it had been noticed that in cesspools

action took place which led to the dissolution of solid matter. aris, where until 1880 various receptacles were largely used by idual householders for the reception of excreta, there might be l "the fosses fixées, from which the matter was raised by me- vessels or vacuum pumps; the fosses sèches, used in the bar- ; the tinettes filtres or filtrantes, which permitted the liquids to e and reduced the refuse to one-fifth part, and the vidange auto- que, invented by Mouras to do away with the necessity for even dic removal of the solids" (Metcalf, 1901). The latter was "a d vault with a water seal, which rapidly transforms all the excre- titious matter which it receives into a homogeneous fluid, only tly turbid, and holding all the solid matters in suspension in the of scarcely visible filaments." The action was attributed to robic bacteria. This tank was introduced by Mouras about , was fully described by Abbé Moigno in the Cosmos les Mondes 881, and was patented in 1882. In 1883 E. S. Philbrick, an rican sanitary engineer, described a tank "in which the solid icles of the sewage may become macerated and finely divided by entation." In 1891 Scott-Moncrieff constructed at Ashtead, land, what he called a cultivation tank, in which sewage was ed to pass upward through a tank containing stone prior to pas- through "nitrifying channels" of coke. The attempt to pro- a purified effluent failed, but it was shown that the first or anae- tank exerted a remarkable dissolving action on the solid con- ents. In 1893 a plant on the same plan was designed for the ugh of Towchester. A year later, in 1894, C. N. Talbot built a ge tank at Urbana, Ill., in which the liquefying anaerobic action observed; and a larger plant, with this definite end in view, was gned for Champaign, Ill., in 1895 and built in 1897.

e anaerobic process of sewage purification owes its practical lopment chiefly to Donald Cameron, of Exeter, England, who s much the same relation to this process that the Massachusetts e board of health holds toward intermittent filtration. In 1895 stalled a water-tight covered basin for the treatment of the sew- of a portion of the city by anaerobic putrefaction and gave it the resque name of the septic tank. The sewage flowed slowly ugh the tank, taking about twenty-four hours in passage, the and outlet being about midway between the top and bottom. ound that the liquid turned dark colored, while in the solids col- d at the bottom an active fermentation was set up. Bubbles inually rose to the surface, carrying with them solid particles, h gathered at the surface to form a scum, sometimes so firm and pact that a man could stand upon it. This scum appeared and ppeared without any recognized reason. Meanwhile the effluent ing off was freed from gross floating matter, and its total solids

and organic constituents were decreased to one-half and two-thi their initial value, respectively. The material removed did however, merely accumulate in the tank, which was operated three years without cleaning. At the end of the first year 25 tons solids had been removed from the sewage, of which it was calculat that 5 tons remained in the tank, and this in the form of a rat stable peaty deposit, only one-third organic in composition (Rid 1901).

The action in the septic tank is probably not the work of str anaerobes, which appear to be rare in sewage, but of organisms a to grow either with or without the presence of oxygen. Under latter condition the nature of their action is characteristic. They fi decompose the solid materials by a lysis, which may or may not hydrolysis (decomposition with the addition of water to the molecule Next they decompose the dissolved molecule, producing gases on th one hand and more stable peaty compounds on the other. Nitrogenou compounds are partially reduced to gaseous nitrogen or free ammonia,

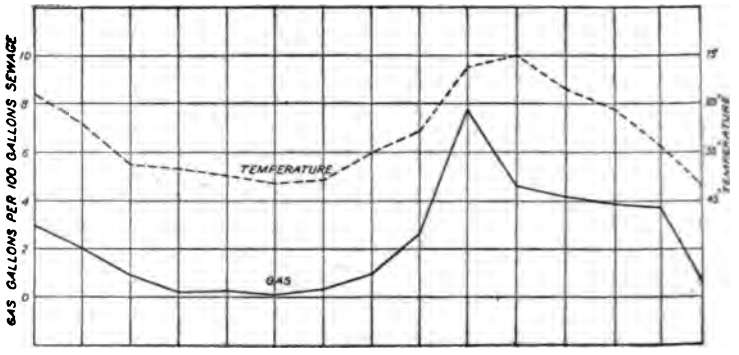


FIG. 4.—Seasonal variation in gas production in the septic tank.

and, together with cellulose, to carbon dioxide and marsh gas. The reaction is an exothermic one, evolving about 8 per cent as much heat energy as is left in the final products (Rideal, 1901). The amount of gas produced in the septic tank was found by Fowler at Manchester (1901) to be 7.5 gallons per 100 gallons of sewage, and Clark (1900) at Lawrence obtained concordant results. Kinnicutt and Eddy (1901), on the other hand, found less than half this amount (2.3 gallons) produced by the septic treatment of the acid-iron sewage of Worcester. The composition of the gas appears to vary widely at different places, but as a rule about three-fourths is methane and one-fifth free nitrogen. The amount of gas produced and, in general, the activity of septic action vary greatly with the temperature. Fig. 4, plotted from the data given by Kinnicutt and Eddy, shows this in a striking manner.

The first septic tanks, like that at Exeter, were covered tightly. It soon appeared, however, that this type of construction is not at all

essary to the maintenance of anaerobic conditions. If sewage be rely allowed to run slowly through an open tank the general reac- is appear to go on just the same. At Manchester the results from ed and open tanks under like conditions showed no marked differ- e, and in similar experiments at Leeds the open tank gave slightly er results, as shown in Table XIV. For promoting anaerobic litions tight covers are therefore needless. Covering has been ocated in order that the gases produced may be utilized for burn- and that the temperature of the sewage may be maintained. The ning of the gases is picturesque but not practically important, and temperature of open tanks is never seriously lowered. At Leeds age in closed tanks lost 0.8°, in open tanks 1.6° F. For the pre- tion of odors and the fly nuisance and for protection against wind rain a light frame roof may often be convenient.

E XIV.—*Results from closed and open septic tanks at Leeds, England (Harrison, 1900).*

[Parts per million.]

	Solids.		Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	
tank:					
Crude sewage	1,710	633	23.6	11.3	124
Effluent	1,110	172	20.6	4.9	54.3
d tank:					
Crude sewage	1,720	666	25.5	12.4	131
Effluent	1,130	197	20	5	69.3

cott-Moncrieff, in his Ashtead experiments, used, as already indi- ed, what was really a septic tank filled with stone. This principle been applied in many other cases to the construction of anaerobic ers, lateral filters, etc., of various types. The so-called "ladder ers" tested at Leeds, formed by a series of trays of stone, from one he other of which the sewage flowed continuously, operated on this ciple—and very badly. At Salford, roughing filters containing -fourth inch to 2-inch gravel were used for continuous filtration at ite of 20 million gallons per acre per day. It was intended to wash se filters by upward flow with artificial aeration, but they have gged seriously (Baker, 1904). At Lawrence a thorough study has n made of various strainers which operate with more or less con- uous flow, of which further particulars are given in the second part his report. All such devices, as well as the anaerobic filters installed ertain sewage plants in the Middle West, act like septic tanks, with additional straining action due to the included material. Against s increased straining action must be set the tendency to clog and difficulty of cleaning.

he most important point in the construction of a septic tank is its e in relation to the flow of sewage which is to pass through it. The

tank is really a sedimentation basin in which the supernatant and the settled sludge both undergo fermentation. The constr of special "hydrolytic" tank that at Hampton (Baker, 19 gratuitous, since the bottom tank necessarily exhibits the lytic phenomena to a high The first requisite is that the should be long enough to all maximum quantity of solids tle out. From laboratory ments on sedimentation it a that this maximum is about cent and that it will be reached by six hours' (Steurnagel, 1904). In p it has often been found that a period is of advantage, perh the liquefaction of suspende of too fine a character to set The Leeds results in Table X cate an appreciably greater r in twenty-four hours than in hours, while further prolong period to forty-eight or seven hours is of no advantag rules of the local governmen require a septic-tank capa one and one-half times th weather flow, and actual l practice generally contemp twenty-four hour period. mingham the septic tanks accommodate only an eigl flow, but ten hours of adc storage are allowed in c tanks and a long conduit. (1902) and other America neers provide shorter period only four to eight hours, an tanks operated on this pr like that at Lake Forest, s work well. On the other short periods of septic tre at Wauwatosa and East Cleveland yield less satisfactory (Winslow, 1905 b).

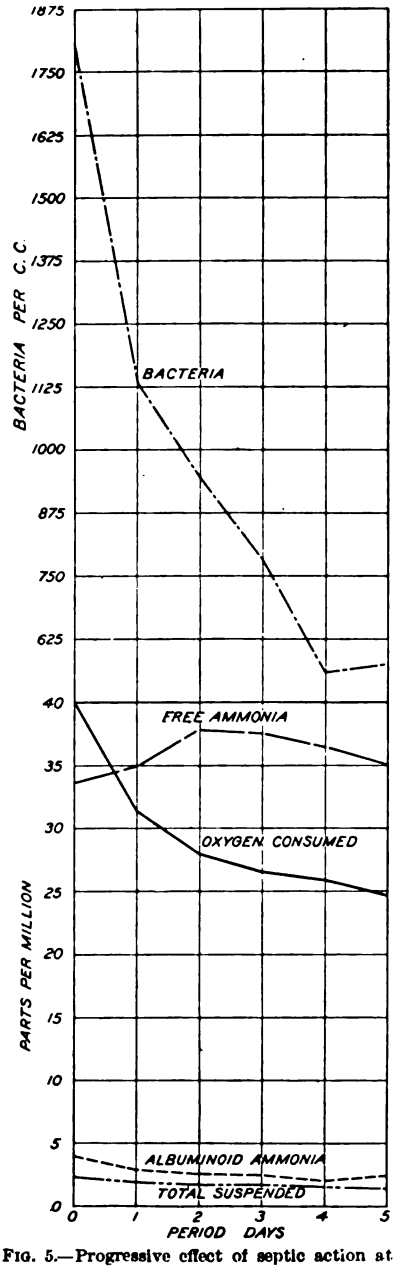


FIG. 5.—Progressive effect of septic action at Lawrence, Mass.

LE XV.—*Average of analyses illustrating the effect of different rates of flow through open septic tanks (Leeds, 1905).*

	12 hours' flow.		24 hours' flow.		48 hours' flow.		72 hours' flow.	
	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).
l solids	1,250	.....	1,110	.....	1,120	.....	1,050	.....
ended solids	272	52	162	71	155	73	141	76
gen as—								
ree ammonia	18.2	22	17.5	24	18.8	19	20.8	37
lbuminoid ammonia	6.3	50	5.2	58	4.5	64	4	52
en consumed in 4 hours 0° F	74.2	45	68.8	49	61.2	55	51.1	55

n interesting experiment was carried out at Lawrence on a small erimental tank with five successive compartments, each equiva- to one day's flow. The results are shown in Table XVI and are ted in fig. 5. They indicate that although a steady change in various constituents takes place the chief purification is accom- hed in the first twenty-four hours.

LE XVI.—*Results of treatment of sewage in septic tank with five successive compartments, each holding one day's flow, April to December, 1903 (Massachusetts, 1904).*

	Analyses (parts per million).					
	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	Bacteria per cubic centimeter.
	Free ammonia.	Albuminoid ammonia.		Organic by Kjeldahl method.		
		Total.	In solution.			
ge	33.8	4.1	2.3	11.6	40.1	1,800,000
ent from first compartment (D-1)	36.1	3	2	.....	31.4	1,100,000
ent from second compartment (D-2)	37.9	2.7	1.9	6.4	28	950,800
ent from third compartment (D-3)	37.5	2.6	1.8	.....	26.6	800,000
ent from fourth compartment (D-4)	36.4	2.2	1.6	.....	25.9	600,000
ent from fifth compartment (D-5)	35.1	2.4	1.5	5.3	24.7	600,000

The septic period should not be too prolonged, since, as will be seen er, the anaerobic fermentation, if carried too far, may produce an uent difficult to nitrify. Furthermore, it is probable that even the erobic action itself may be checked by the concentration of waste ducts in too long a period. The marked decrease in bacteria in ble XVI indicates some such toxic action. An earlier Lawrence periment is also suggestive. A small septic tank was dosed, not h sewage, but with the more concentrated sludge from settled vage. For six months the storage period was from five to fifteen ys and sludge accumulated, filling up 60 per cent of the tank. The e was then increased, so that the storage period was reduced to ty-nine hours, when the accumulated sludge decreased to 8 per t and did not further increase for a year (Massachusetts, 1901). Leeds it was found that a seventy-two-hour septic period inter- ed with the solution of sludge (Leeds, 1905). Clark and Gage

(1905) have found that certain types of bacteria specially active sewage purification increase during the first twenty-four hours septic treatment and then fall to numbers smaller than are presen raw sewage. It seems possible that too long a period of action actually favor the accumulation of sludge while producing an effl hard to nitrify. Alvord (1902) for these reasons suggests the u an "elastic tank" with separate compartments, which can be incl in or thrown out of the system to adjust it to varying conditio flow and temperature.

The results of septic treatment in three English cities and at l rence, Mass., are shown in Table XVII, and in Table XVIII is an interesting example of septic action on an intensive scale.

TABLE XVII.—*Effect of septic treatment.*

Place.	Material.	Solids.		Nitrogen as—		Oxygen consumed.		Remar
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Total.	Dissolved.	
Exeter	Sewage	778	350	44.4	.....	29	.....	April to Ju
	Tank effluent	593	154	32.5	.....	20.1	.....	
Leeds	Sewage	1,690	622	24.7	11.7	127	.....	February,
	Tank effluent	1,090	183	21	5.2	58.5	.....	January
Birmingham	Sewage	1,967	676	31.9	13.7	153	76.1	Septic tank 1901, ope
	Tank effluent	1,399	245	43.3	18.7	108	68.5	
Lawrence	Sewage	769	232	38.1	7	49.5	.....	Tank A, J 1898, to J 1903.
	Tank effluent	597	107	37.7	3.3	27.3	.....	

NOTE.—Oxygen consumed in four hours at 80° F. in the English results; in two minutes' bo Lawrence. Solids in Lawrence figures for year 1902 only.

Table XVIII shows the results obtained with an experimental at Brockton, Mass., in the treatment of very strong sewage pu from the bottom of the receiving well during the last portion c brief daily period of pumpage. The period of septic action twenty-four hours. The results indicate a very high rate of pu tion. Bolling figures that of the suspended solids entering the 45 per cent remained as sludge, 6 per cent escaped in the effluer per cent went into solution, and 33 per cent disappeared a (Barbour, 1904).

TABLE XVIII.—*Results of treatment of sludge at Brockton, Mass., August and Sep 1900 (Barbour, 1904).*

[Parts per million.]

Material.	Volatile residue.		Fixed residue.		Nitrogen as—			Oxygen sum
	Dissolved.	In suspension.	Dissolved.	In suspension.	Free ammonia.	Albuminoid ammonia.		
						Total.	Soluble.	Total.
Sludge	229	1,810	271	555	34.5	42	3.9	396
Effluent	285	116	299	31	44.1	7.5	4.6	122

n comparing the work of the large English tanks, shown in Table 'II, it will be noticed that the effect on free ammonia varies, this ıstituent sometimes decreasing appreciably, as at Exeter, but gen-ılly remaining fairly constant. Sometimes, as at Worcester, it ıibits a marked increase. The reactions in the septic tank naturally :y materially with the original composition and age of the sewage. a very fresh sewage there is always a considerable formation of free monia by the decomposition of more complex organic bodies. If s process has been completed when the sewage is subjected to ·tic treatment a decrease in free ammonia may be expected in the ık. Albuminoid ammonia and oxygen consumed in each case fall one-half or two-thirds of their initial value. The evidence accu-lated by the royal sewage commission indicated that an increase free ammonia is the general rule in English septic tanks, while the uminoid ammonia is reduced 38 to 54 per cent at Exeter, 50 per ıt at Leicester, and 36 per cent at Birmingham. The oxygen con-ned was reduced 25 to 33 per cent at Exeter, 50 per cent at Accring-ı, 50 per cent at Leeds, 36 to 60 per cent at Leicester, and 29 per ıt at Birmingham (Martin, 1905). A curious phenomenon in cer-n septic tanks is the presence of oxygen or highly oxygenated com-ınds in the effluent in spite of the active reduction which takes ce in the tank. Thus Barwise (1904) notes the occasional presence nitrates and nitrites (up to 1 part per million) in the septic effluent Exeter, and at Burnley after twelve hours' treatment in the septic ık oxygen was present to the extent of 1 to 3 per cent of saturation l nitrates up to 10 parts per million.

The most important practical result of septic treatment is the noval of suspended solids. Tanks at Exeter, Leeds, and Birming-m, as noted in Table XVII, show a reduction of 56, 71, and 64 per ıt, respectively. At Leicester the removal has ranged from 60 to 70 : cent. At Lawrence 181 parts per million of suspended solids re reduced to 73 parts, a removal of 61 per cent (Massachusetts,)4). Experiments on London sewage at the Crossness outfall ›wed that six hours' sedimentation in what was really a septic tank ve a reduction from 281 to 125 parts of suspended solids (Novem-r, 1900, to March, 1901) and in another series (March to October,)1) from 253 to 143 parts, a removal of 56 and 43 per cent, respec-ely. These London results illustrate the gradual increase in sus-nded solids discharged in the effluent, which is sometimes noticed ring the first year of a tank's operation. At Leeds 127 parts peared in the septic effluent from March to June, 1899, 156 parts ›m July to October, and 213 parts from November, 1899, to Feb-ary, 1900 (Leeds, 1900). At Huddersfield the septic effluent con-ned 66 parts in August, 1900, 82 parts in September, 113 parts in

October, 122 parts in November, and 117 parts in December (R. S. C., 1902 b).

The action of the septic tank on dissolved solids is a variable one, as shown in Table XIX, taken from Kinnicutt, with the addition of figures from a recent Lawrence report.

TABLE XIX.—*Removal of solids by the septic tank (Kinnicutt, 1902; Clark, 1904).*

Place.	Solids removed (per cent of total).	
	Dissolved.	Suspended.
Exeter	− 2.57	56.01
Lawrence	2.12	61.60
Leeds	12.05	70.37
Manchester	15.45	57.06
Worcester	20.67	25.57

It will be noticed that a slight removal of dissolved solids occurs, except at Exeter, reaching a considerable amount at Worcester. The phenomena in the case of Worcester are peculiar on account of the acids and iron salts in the sewage. In the first place all the reactions are hindered by the antiseptic action of these substances. The reduction of albuminoid ammonia is small, only 20 to 25 per cent, the gas production is only half that at Lawrence and Manchester, and the liquefaction of sludge is imperfect. In the second place the proportionate decrease of suspended solids is small and of dissolved solids great on account of the reduction and precipitation of iron compounds.

Granting that the septic tank effects a removal of 60 to 70 per cent of suspended solids under favorable conditions, the fate of the matter retained must next be determined—how much is stored as sludge and how much is reduced to liquid or gaseous form. Evidence before the royal sewage commission indicates a destruction of the stored solids, amounting to 26 per cent at Manchester, 25 per cent at Birmingham (too low a figure, since a great deal of reducible sludge is removed from sedimentation chambers cleaned out weekly), 20 to 60 per cent at Leeds, 30 per cent at Sheffield, 35 per cent at Accrington, 40 per cent at Huddersfield, 50 per cent at Glasgow, and 80 per cent at Exeter (Martin, 1905). At Saratoga the septic tank destroys 40 per cent of its sludge (Barbour, 1904). This value will naturally vary widely according to the ratio of organic to inorganic solids in the sewage, the inorganic solids being much less likely to disappear. In the London experiments the destruction of total sludge was 41 per cent and of organic sludge 71 per cent (Dibdin, 1903). At Hampton 58 per cent of the organic sludge was destroyed (Baker, 1904).

Practical experience with septic tanks yields widely varying results with regard to the destruction of stored solids, as indicated by the necessity for emptying the tanks and removing sludge. At Exeter

Cameron's original tank was operated for eight years without cleaning, but from the present installation, with a fourteen-hour period, sludge is pumped out once a month. At Barrhead a tank has been in use for six years (twenty-four-hour period) without cleaning and with little deposit. At Acton (sixteen hours) a tank has been operated for fifteen months with no deposit. At Yeovil (twenty-four hours), Burnley (twelve hours), Sutton (five hours), and Accrington (twenty-eight hours) it has been found necessary to remove sludge about once a year. At Oldham the tank is cleaned every two or three months (Baker, 1904). American plants exhibit similar variations. The Lawrence tank has not been cleaned for six years, and in 1903 was less than half full of accumulated sludge. At Marion a twenty-hour tank worked for two and one-half years without emptying. At Mansfield, with a twenty-four-hour period, admirable results have been obtained, only an insignificant amount of sludge having accumulated after three years of use. At Plainfield solids accumulate in the form of scum rather than sludge and are removed several times a year. Sludge and scum are probably largely interchangeable, a slight difference in specific gravity determining the destination of the solids (Barbour, 1904). At Lake Forest (four hours), the tank has been operated for three years without cleaning, while at Wauwatosa (ten hours) the tank is emptied twice a year (Winslow, 1905 b). Of conditions in Ohio, Pratt (1904) said in 1903:

> There are now in use 10 septic tanks, while plans for 14 more have been made. The present tanks have been in operation from one to five years. As sludge destroyers they have been fairly successful, but in a few cases offensive odors are created, and in some the effluent from the tank is probably not in the best possible state for subsequent oxidation in the filters. As far as can be learned the tanks have continued in use from one to two years without decreasing in capacity more than 25 per cent. The scum formed at the surface and bottom accumulation appears to remain fairly constant after reaching a certain volume; but a change in the composition of the sewage or in other conditions may cause a rapid increase in the deposits.

On the whole, it seems necessary to conclude with Baker (1904) that "in the majority of septic tanks thus far built for municipalities the sludge must be removed at intervals of a year or less." In certain special cases, as at Exeter and Mansfield, unknown conditions intervene to cause a more complete destruction of the stored solids.

The chief purpose for which the septic tank has been introduced is the diminution of suspended matter and the consequent lightening of the sludge burden. It is claimed by some experts that in addition to this action the anaerobic putrefaction brings the soluble constituents into a form in which they are more easily acted on by the nitrifying organisms. Martin, Cameron, and Fowler all expressed this opinion before the royal sewage commission (Martin, 1905). The writers are not aware of any data which support this contention. Harding and Frankland (Martin, 1905) are skeptical as to such an

advantage and Dibdin (1904) wholly disbelieves in it. On the other hand, it is probable, as was shown before the royal sewage commission, that when not accurately regulated, "the anaerobic process may be carried too far, so as to interfere with the subsequent aerobic action" (Dibdin, 1903). Martin and Rideal minimize such interference, while Scott-Moncrieff, Woodhead, and Fowler consider it of great importance (Martin, 1905). It appears certain that with strong sewage the putrefactive process may be carried so far that its products will check the aerobic organisms. In experiments at Caterham an effluent was obtained containing 1,260 parts per million of dissolved solids, 288 parts of nitrogen as free ammonia, and 53 parts of organic nitrogen, which would not undergo nitrification until diluted (Rideal, 1901). Experience at Andover leads to the same conclusion. Here the sewage is strong and already twenty-four hours old when it reaches the disposal area. Most of it is discharged on sand beds without further treatment. While the beds were successfully handling raw sewage at a rate of 0.03 million gallons per acre per day, a small filter gave poor results with septic effluent at a rate of 0.04 and very bad results when the rate was increased to 0.1 (Clark, 1900).

From a general review of the results cited above it is not easy to determine just how much is to be gained by the introduction of the septic tank in a sewage-disposal system. With a small plant receiving very fresh sewage from a small town or an institution, it is of great advantage in breaking up masses of fecal matter. In such plants and in those which handle considerable quantities of manufactural waste the equalization of flow and composition may be of much importance. The latter factor, for example, carried weight at Manchester. These, however, are special cases. The chief point is that by proper septic treatment 60 to 70 per cent of the solids in sewage may be removed. When such a removal is necessary before final aerobic treatment, the septic tank will generally be found the best means for effecting it. Compared with chemical precipitation it has the advantage that its sludge is less in amount, besides the fact that the cost of chemicals is saved. Experiments at Oldham (R. S. C., 1902 b) pointed clearly to the superiority of the treatment without chemicals, and at Birmingham the substitution of septic tanks for precipitation resulted in a saving of $20,000 per annum and a decrease of 25 per cent in sludge (Watson, 1903). Whether any preliminary removal of solids is always desirable before final aerobic treatment is believed to be by no means certain. English authorities strongly tend to the opinion that such treatment is necessary. Rideal (1901) holds that an anaerobic stage is necessary in the process of sewage purification, although he admits that it may be accomplished in long sewers without special treatment. Ward and Woodhead maintain

that the destruction of cellulose in particular can be accomplished only under anaerobic conditions (R. S. C., 1902 c). Scott-Moncrieff, Whittaker, Stoddard, and Fowler (Martin, 1905) all hold the process to be necessary. The practical data on which these conclusions are chiefly founded are discussed on pages 63–64. These data are in general the results of experiments at Leeds, Manchester, and other cities which showed that aerobic filters of large material, worked as contact beds, tended to clog badly when treated with crude sewage, while they worked well if the sewage was previously septicized. Experiments on coarse filters through which sewage is allowed to trickle continuously have suggested, on the other hand, that crude sewage may sometimes be successfully treated at rapid rates and settled later after it has been nitrified. There are numerous examples in nature of the destruction of organic matter by purely aerobic processes. Even cellulose is most actively attacked just at the surface of the ground, as evidenced by the decay of fence posts. Dibdin (1904), almost alone among the English sanitarians, has recently taken a strong position against the theory that the decomposition of cellulose must necessarily be anaerobic. The writers are of the opinion that the anaerobic process has not been shown to be a universally necessary step in the process of purification. In many plants it will no doubt prove useful. In other cases, however, a short preliminary sedimentation without septic action or subsequent sedimentation of a trickling effluent obtained by the treatment of crude sewage may be more economical.

In the eastern part of the United States, where ample areas of sand of the right quality are available for intermittent filtration, the use of the septic tank is rarely held to be necessary. In most cases the solids are discharged directly on the surface, where they are partly oxidized and partly accumulate as sludge. In the Middle West, on the other hand, where sand areas are limited and rates must be high, the use of the septic tank is very general. Barbour, Alvord, and Shields are all strong advocates of the practice, and the plants they have installed work very satisfactorily at higher rates than those in use with raw sewage in Massachusetts. At Saratoga (Barbour, 1905) the rate is 0.1, at Lake Forest it is over 0.4, and at the Wauwatosa county institutions 0.4.

PURIFICATION OF SEWAGES BY THE CONTACT PROCESS IN BEDS OF COARSE MATERIAL.

It has been shown that the scientific development of the process of purifying sewage by the action of oxidizing bacteria really dates from the experiments conducted at Lawrence, Mass., under the direction of Hiram F. Mills. The direct application of the method of *intermittent filtration* is, however, rather narrowly limited by

the whole conception of sewage purification. With
there was little true "filtration," and it became e
bed was really not a filter, but an oxidizing mach
resistance could no longer be depended on to delay t
the bed sufficiently to allow purification to occur.
sary, therefore, to regulate the rate by constructing
ters, in which the sewage could be retained in c
filling material and its accumulated growth of r
Hence this type of purifying plant was called the
It operated with success, attracted wide attention, a
design of numerous so-called "biological filters" on si

W. J. Dibdin, chemist to the London county cou
the first English sanitarians to grasp the essential p
age purification. In studies of the self-purification
H. C. Sorby had pointed out as early as 1883 the
living organisms, although he had in view chiefly t
of solids by the larger microscopic forms. In 188
step further in affirming the relation of organic lif
tions which take place in a purifying stream. D
been associated with both these observers, read a p
Institution of Civil Engineers in 1887, in which he
whole theory as follows:

In all probability the true way of purifying sewage, where suitable
will be first to separate the sludge, and then to turn into the effl
proper organism, whatever that may be, specially cultivated for the

to employ. Four wooden tanks were installed at the northern (Barking) outfall. Each was 5 feet deep and had an area of one two-hundredth of an acre, and they were filled, respectively, with burnt clay, pea ballast (Lowestoft shingle), coke breeze, and a combination of gravel and sand over a layer of proprietary material. All received effluent from the chemical precipitation tanks at an average rate of 0.4 million gallons per acre per day. Sewage was allowed to run through continuously for eight hours, the rate being controlled by partially closing the outlet valves, and the beds were allowed to stand empty for aeration during the remainder of the twenty-four hours. The coke breeze, as indicated in Table XX, proved most satisfactory, the coarser burnt clay yielding a much poorer effluent, and the sand clogging seriously and giving a clear but imperfectly purified filtrate.

TABLE XX.—*Results of filtration through various coarse materials, London experiments, first series, May to August, 1892 (Clowes and Houston, 1904).*

[Parts per million.]

	Oxygen consumed in 4 hours at 80° F., filtered.	Albuminoid nitrogen.
Chemical effluent	20.1	2.7
Effluent from filter No. 1 (burnt clay)	11.6	1.3
Effluent from filter No. 2 (pea ballast)	9	1.3
Effluent from filter No. 3 (coke breeze)	7.2	1.1
Effluent from filter No. 4 (sand, etc.)	7	.8

Coke breeze was fixed on as the best material for further experiments, and a second series was begun to study the details of practical operation on a larger scale. A filter bed 1 acre in area, consisting of 3 feet of pan breeze covered with 3 inches of gravel, was constructed at Barking and put into operation in September, 1893. At first the bed was dosed too heavily and soon became clogged and foul. The need for rest and aeration, especially when a new filter is first operated, was thus clearly shown. After three months' rest the bed could handle two fillings a day, the sewage being allowed to stand in it for a period of from one to two hours. The cycle finally established allowed one and one-half hours for filling the bed, two hours for standing full, two and one-half hours for emptying, and six hours for aeration. When gradually worked up to its full capacity sewage could be treated at a rate of 1.2 million gallons per acre per day; the purification effected by the filter suffered no reduction with age; and the analytical results were excellent, as indicated in Table XXI.

TABLE XXI.—*Results of contact treatment at London, acre filter (Clowes and Houston, 1904)*

[Parts per million.]

Period.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
			Free ammonia.		Nitrates.	
	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.
September-December, 1893	59	17	4.8	1.4	1.6	1.9
April-June, 1894	59	12	4.9	1.1	1.8	3.4
July-November, 1894	52	10	4.7	1.3	.3	2
January-March, 1895	61	14	4.8	1.4	5.4	9.7
April-September, 1895	46	9	4	1.3	2	7.6
May-June, 1897	31	6	3	.9	.6	4.1
1900-1901	55	9	.....	.....	.4	10

The early London experiments of Dibdin have been greatly extended since 1898 by Clowes and Houston. Various details of construction and operation were worked out at both the Barking and Crossness outfalls, and the recommendation was finally made that the present plan of chemical treatment be abandoned and that the London sewage be, first, settled to remove gross mineral matter; second, septicized for six hours; and, third, treated in single contact beds of coke, 12 feet deep, at a rate of 5.2, attained by four fillings per day (Clowes and Houston, 1904).

In 1894, as a result of the first Barking experiments, Dibdin installed seven experimental contact beds at Sutton, in Surrey. Here two important modifications of the contact system were introduced. In the first place, the sewage was subjected to successive treatments, first in coarse and then in finer-grained beds—the "double contact" system. In the second place, after the process had worked well with chemical effluent, as it had done at London, the treatment of crude sewage was attempted. Beginning November, 1896, a double-contact system treating crude sewage was operated for the first time. The depth of the beds was 3 feet 6 inches, and the filling material burnt ballast, larger than three-eighths inch. Two fillings a day were made, giving a rate on each individual bed of 0.9. The analytical results showed a reduction of oxygen consumed from 76 parts per million in the sewage to 26 parts in the effluent of the first bed and 10 parts in the effluent of the second bed (Dibdin, 1903). The system worked for five years with admirable results. At present sewage is carefully screened (2 to 3 tons of solids per million gallons being removed) and then treated in primary coarse beds of burnt ballast and secondary fine beds of coke breeze, at a combined rate (based on the area of both sets of beds) of 0.36. It is calculated that the cost of operation is only about $20 per million gallons, as against $75 for the original treatment with iron sulphate and lime (Rideal, 1901).

eneral principles of the contact system being thus established, ıes necessary to work out details of construction. One of the these details concerns the nature of the filling material. In ton tanks it was found that burnt clay gave somewhat better than the other substances, although it tended to break down Granite and slate proved more permanent (Thudichum, 1903). ortant series of experiments carried out at Barking and Cross- 1898–1901 showed that for treating London sewage coke was le to stone, as indicated in Table XXII.

XII.—*Results of contact treatment at London (Barking), 1898–1901 (Clowes and Houston, 1904). Analyses of effluents.*

[Parts per million.]

Period and treatment.	Suspended solids.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—	
		Total.	Dissolved.	Nitrites.	Nitrates.
1898, to April, 1899:					
ewage		145	54	0.2	1.3
contact, ragstone, 6 feet		32	28	1.6	21.7
contact, coke, 6 feet		24	20	.7	12.5
899: Sept. 21, 1899, to May 19, 1900:					
ewage	661	124	63	.2	1.1
contact, coarse coke, 10 feet	73	38	23	1.2	10.2
contact, coarse and fine coke, 10 feet	31	23	18	.6	21.8
, to Aug. 10, 1901:					
ewage	667	129	68	.1	.4
ank A	177	84	54	.0	1.7
coke bed, 6 feet	100	51	33	.4	7.5
ank B	139	82	53	.0	1.3
ke bed, 6 feet	32	37	76	.6	12.9

n and Thudichum report a series of studies summarized in XXIII which again indicate the superiority of coke.

XIII.—*Comparison of filtering material (mean values) (R. S. C., 1902 a). Analyses of effluents.*

[Parts per million.]

Material.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	
	16.6	0.58	0.94
	23.4	1.04	1.52
	23.8	.12	1.55

ıwrence, also, by far the best results have been given by coke. materials give better qualitative results than smooth mate- Broken-stone filters have not been particularly efficient (Mas- tts, 1903). The general results obtained at Lawrence on sin- act filtration are shown in Table XXIV.

TABLE XXIV.—*Results of single-contact treatment at Lawrence, Mass.* (*Fuller*, 1905)

No. of filter.	Material.	Depth (inches).	Preliminary treatment.	Rate (million gallons per acre per day).	Analyses (parts per million)					
					Sewage.			Effluent.		
					Nitrogen as—		Oxygen consumed.	Nitrogen as—		
					Free ammonia.	Albuminoid ammonia.		Free ammonia.	Albuminoid ammonia.	Nitrates.
103	¼- to ½-inch coke.	60	Septic	0.6	38.7	3.3	27.3	7.9	0.9	21.2
107	Cinders	24	None	.55	23.8	4.6	34.5	13.4	1.7	5.4
135	½- to 1-inch stone	214	None	1.2	37.8	5.6	49.5	20.3	1.7	3.4
154	Coke, breeze	48	Septic	.5	58.7	6.6	45.4	42.3	2.2	3.0
167	Stone (walnut)	48	Septic	.3	85.3	8.5	65.9	54.6	3.2	13.4
176	¼- to 1-inch coke.	60	None	.7	37.2	6.1	42.8	13.1	1.5	11.3

At Birmingham it was found that the purification, measured reduction in oxygen consumed, was 64 per cent with broken stone per cent with slag, and 93 per cent with coal (Bredtschneider Thumm, 1904). There is some evidence (see p. 82) that coal ex a specially favorable action in trickling filtration (Hill, 1897). Manchester (1901) materials containing iron were found to yield ticularly good results. At Hamburg it appeared that the amoun porosity is immaterial and that the chief desideratum is iron cont Thumm, by the addition of 1 per cent iron to gravel or pumice, creased the purification in two contact beds from 46 and 42 to 66 62 per cent, respectively (Thumm, 1902).

A series of experiments on various materials conducted by Zah Charlottenburg in 1901 showed that brick gave the best results, lowed by slag, coal, coke, and gravel in the order named. The res are brought together in Table XXV. In each case the secondary filter was operated as a contact bed, the sewage standing on it u a head during the full period. It acted chiefly as a strainer to ren suspended solids.

TABLE XXV.—*Results of Charlottenburg experiments on contact filtration* (*Zahn*,

[Parts per million.]

	Total solids.		Suspended solids.		Nitrogen as—			O
	Total.	Loss on ignition.	Total.	Loss on ignition.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Raw sewage	1,121	294	413	272	65	19	0	
I. a. Slag	1,059	163	82	54	22	11	Present	
I. b. Sand	1,068	149	0	0	17	7	do	
II. a. Coke	1,028	159	38	22	36	9	do	
II. b. Sand	1,044	177	0	0	24	7	do	
III. a. Gravel	1,084	203	101	68	32	12	do	
III. b. Sand	1,137	235	0	0	20	6	do	
IV. a. Brick	1,229	173	39	20	21	8	do	
IV. b. Sand	1,280	204	0	0	18	8	do	

In general, these results with regard to kind of material are somewhat inconclusive. Coke and coal seem particularly favorable and the presence of iron is apparently important. Cameron and Harding consider smoothness of surface desirable (R. S. C., 1902 a), but this conclusion is scarcely borne out by the successful use of coke.

The nature of the material used will necessarily depend much on local conditions. Its size is more a matter of choice and this factor is of even greater practical importance. Reference to the Hamburg results in Table XXVIII illustrates this point. It will be noticed that one-eighth to five-sixteenths inch material in experiments B and C gave twice as much purification as three-eighths to 1⅛ inch material in experiments L, M, N, and P. The high purification in these beds was, however, accompanied by great loss of capacity. At the royal testing station at Berlin, it was found in experiments with several different sewages that one-third to 1 inch slag for the first contact and one-eighth to one-third inch slag for the second contact gave the best results. The primary beds effected a purification of 20 to 30 per cent. The secondary beds raised this figure to 70 per cent and produced a nonputrefactive effluent (Thumm, 1902). Clowes and Houston (1904), as a result of their London experiments, recommended the use of "walnut-size coke." In evidence before the royal sewage commission, Fowler recommended one-eighth inch material, Cameron one-eighth to one-half inch, Frankland one-eighth to three-fourths inch, and Dibdin one-half to 4 inch for first contact and one-sixteenth to three-eighths inch for second contact (Martin, 1905). Barwise (1904) suggests the use of coarser filling—3 to 5 inch material for primary beds and one-half to 1½ for secondary beds to treat septic effluent. An interesting suggestion has recently been made by Dibdin (1904), who recommends the construction of "multiple-surface bacteria beds" of tiers of slate or brick regularly built up so as to secure a liquid capacity sometimes reaching 80 per cent. A bed built at Devizes on this plan is said to have cost less than one-third as much as an ordinary coke bed. Analyses from such a bed are shown in Table XXVI.

TABLE XXVI.—*Results from multiple-surface bacteria bed, February 9 to March 25, 1904 (Dibdin, 1904).*

Average number of fillings per day		0.83
Nitrogen as albuminoid ammonia:		
In sewage	parts per million	9.9
In effluent	do	4.8
Oxygen consumed in 4 hours at 80° F.:		
In sewage	do	76.6
In effluent	do	58.7

If a bed were filled with perfect spheres of uniform size its open space or water capacity would be 26 per cent of its original cubic capacity. In beds built of the ordinary materials actually used this

value varies from 30 to 50 per cent. With progressive use the capacity decreases, and this is one of the most serious problems in the operation of the contact bed.

In an admirable analysis of the causes which affect the loss of capacity in contact beds the Manchester experts (Manchester, 1902) arrange them under the following five heads:

(*a*) Settling together of the material.
(*b*) Growth of organisms.
(*c*) Impaired drainage.
(*d*) Insoluble matter entering the bed.
(*e*) Breaking down of the material.

The first cause must always operate to a considerable extent and in part accounts for the great initial loss when the bed is first put in operation. If the original liquid capacity is determined, not by filling with water and measuring the effluent, as should be done, but by measuring the amount of water or sewage required to fill it, the initial loss will appear much larger than it really is, by the amount of water required to saturate the surfaces and pores of the dry material. The relative importance of this initial loss and of the true loss due to settling, growth, etc., is indicated in Table XXVII.

TABLE XXVII.—*True and apparent loss of capacity in a contact bed (Martin, 1905).*

	Capacity.	
	Gallons.	Per cent of total.
Total cubic contents	23,431	100
First filling, Aug. 15, 1896	13,775	59
Filling Aug. 21, 1896	10,302	44
Filling Nov. 14-15, 1896	7,893	34

The actual decrease in capacity after the first filling is partly due, as noted above, to the breaking down of uniform materials into pieces of more varied size which become more closely packed together. The amount of this loss may be measured by the space left by the settling over the top of the material. At Pawtucket it was estimated that about one-third of the total capacity loss in eighteen months was due to this factor. Such loss may be avoided to a great extent, as has been pointed out above, by the use of compact and permanent filling. This was shown very clearly in the Hamburg experiments. Table XXVIII shows, by a comparison of experiment G with H and I and of experiment N with M and O, that slag, while giving as good analytical results as coke and gravel, showed appreciably less loss of capacity.

TABLE XXVIII.—*Statistics of Hamburg experiments on contact filtration (Dunbar and Thumm, 1902).*

No. of experiment.	Material.		Kind of sewage received.	Number of fillings per day.	Length of run (months).	Oxygen consumed in 10 minutes' boiling.		Capacity (parts per million).		Remarks.
	Kind.	Size (inches).				Sewage.	Effluent.	Original.	Final	
B.....	Slag.....	¼ to $\frac{1}{16}$	Raw.....	1	26	96	27	33	20	
C.....	.....do....	¼ to $\frac{1}{16}$	.....do.....	2	14	91	21	41	15	
[illegible].....	Coke.....	⅜ to 1¼	.....do.....	6	15	80	52	38	[a] 30	Washed twice.
D.....	Slag.....	¼ to $\frac{1}{16}$	Effluent from L.....	3	15	80	20	43	17	
E.....	Gravel....	¼ to $\frac{1}{16}$	.....do.....	2	11	80	19	27	14	Washed once.
F.....	Coke.....	¼ to $\frac{1}{16}$	.....do.....	2	15	80	19	36	22	
G.....	Slag.....	$\frac{1}{16}$ to ⅜	Effluent from N.....	3	11	90	30	39	23	
H.....	Coke.....	$\frac{1}{16}$ to ⅜	.....do.....	3	11	90	27	39	22	
I.....	Gravel....	$\frac{1}{16}$ to ⅜	Effluent from M (4 months) and P (7 months).	3	11	90	28	31	19	
K.....	Gravel + 1 per cent iron turnings.	$\frac{1}{16}$ to ⅜	Effluent from M.....	3	11	90	29	31	19	
M.....	Coke.....	⅜ to 1¼	Raw.....	3 to 6	12	88	63	44	28	
N.....	Slag.....	⅜ to 1¼	.....do.....	3 to 6	12	88	65	48	39	
O.....	Gravel....	⅜ to 1¼	.....do.....	3	12	88	48	35	26	
P.....	Brick.....	⅜ to 1¼	.....do.....	3	12	88	46	34	28	

[a] Fell to 18 per cent before last washing.

In England the loss of capacity due to breaking down of material has been found to be serious with clay not thoroughly burnt, and the need for permanent filling has led to an extensive use of various sorts of furnace clinker. Many English beds are, however, still built of friable stuff. Baker (1904) says: "It seems strange to an American to see so much perishable material used for filter beds," and suggests that in the United States gravel or broken stone will probably be preferable to cinders, clinker, or brick.

The capacity loss due to impaired drainage, like that from the breaking down of material, may be controlled to some extent by proper construction of the beds. The other two losses, due to growths and to deposition of solids, are more or less inevitable.

The loss of capacity due to the growth of organisms is more or less directly correlated with an increasing purifying power of the bed. At Manchester it was found that "the chemical efficiency is increased by a loss of capacity. These beds purified four doses after they had become partly clogged as readily as three when clean. The amounts were about the same in the two cases." (Manchester, 1899.) Dunbar gives the figures quoted in Table XXIX to illustrate this point. He considers that the ability of the filter to absorb rapidly free ammonia from the sewage is an index of the amount of growth within the filter.

TABLE XXIX.—*Improvement in ammonia absorption in a contact filter (Dunbar and Thumm, 1902).*

Months at work.	Loss in ammonia (per cent).	
	Single filling.	Double filling.
1	9.1	14.6
2	34.6	30.9
5	35.2	23
8	47.4	41.3
10	43	41.2
14	40.5	41.6

This sort of loss due to growth is almost independent of the character of the liquid filtered. Dunbar treated coke contact filters with various substances (134 fillings in four months) and found with tap water a reduction in capacity from 48 to 40 per cent; with tap water plus 1 per cent urine, from 47 to 37 per cent; with unfiltered sewage from 48 to 37 per cent; with filtered sewage, from 48 to 40 per cent, and with sewage precipitated with lime, from 44 to 36 per cent (Dunbar and Thumm, 1902).

The loss of capacity due to the deposition of the insoluble mineral matter which enters the beds is also serious and in England has necessitated the complete renewal of many contact filters. It may be avoided to a considerable extent by preliminary straining and sedimentation, and it tends to be concentrated in the upper layers of the filter. With some sewages, however, it seems clear that contact filters will require frequent renewal. The experiments at Leeds furnish a good example of this. Table XXX indicates a reduction to values as low as 9 and 11 per cent. It appeared evident to the experts in this case that in order to treat Leeds sewage in contact beds it was necessary to use an even, hard filling material, to remove suspended mineral matter by careful sedimentation, and to exclude iron compounds from the sewers. Even then they considered the permanency of the beds more than doubtful.

TABLE XXX.—*Loss of capacity in contact beds at Leeds—raw and settled sewage (Leeds, 1905).*

No. of bed.	Material.	Period.	Original capacity (per cent).	Final capacity (per cent).
1	Coke, not less than 3 inches	Oct. 2, 1897, to Oct. 7, 1899	48	15
3	Clinker, ½ to 1 inch	Nov. 19, 1898, to Jan. 10, 1901	51	14
5	Clinker, 1 to 2 inches	Feb. 27, 1899, to Dec. 30 1900	52	11
7	Clinker, ⅝ to 1 inch	Mar. 8, 1899, to Feb. 15, 1901	31	9
8	Clinker, ⅝ to 1 inch	Mar. 30, 1898, to Sept. 1, 1899	31	12

It is possible to restore the original capacity of contact beds to a considerable extent by allowing them to rest empty for several weeks Table XXXI shows how efficient this process was at York and at Leeds in the case of two of the beds above referred to. Rest can of

effect only the disintegration of the organic growth and can not the accumulated mineral matter. The restoration of capacity erefore never be complete.

TABLE XXXI.—*Loss in capacity of contact beds and its recovery by resting.*

NABURN DISPOSAL WORKS, YORK (YORK, 1901).

	U. S. gallons.	Per cent open space.
Bed No. 1.		
acity	55,200	100
uid capacity	22,300	40
lays' work	11,200	20
lays' rest	16,400	30
lays' work	11,500	21

KNOSTROP SEWAGE WORKS, LEEDS (LEEDS, 1900).

Bed No. 7, single contact.		
acity	222,000	100
uid capacity	66,800	31
days' work	25,900	12
lays' rest	64,200	30
days' work	30,700	14
Bed No. 8, single contact.		
acity	113,000	100
uid capacity	35,400	31
days' work	12,800	11
lays' rest	32,300	28
days' work	11,800	10

treatment of septic effluent instead of crude sewage greatly pro- he life of the contact bed. In the Barking experiments (Clowes ouston, 1904) the capacity of two primary coke beds fell in ten s from 69 and 70 per cent to 20 and 18 per cent, respectively. lary beds showed only a reduction from 62 to 51 per cent e) and from 53 to 44 per cent (fine). The stone beds lost about cent of their original liquid capacity per week. A series of ex- nts with septic effluent followed, in which after the first loss a ty of about 30 per cent was constantly maintained. At Leeds found that beds taking septic effluent showed much higher ties than those which received crude sewage. Similar conclu- were drawn by the experts at Manchester, although the experi- made with crude sewage were not exhaustive. The capacity s treating septic effluent decreased during the first three months en remained fairly constant at about 33 per cent (of the original contents), as shown in fig. 6. At Burnley, with septic effluent, pacity of contact beds fell from 44 to 19 per cent; at Exeter it m 39 to 28 per cent, and at Leicester from 49 to 29 per cent. tton a minimum of 21 per cent was reached (R. S. C., 1902 a). dham "no clogging" was reported after two years (Oldham, In still other places even crude sewage has been treated with s. At West Bromwich the capacity of primary beds fell from 33 *er cent and of secondary* beds from 33 to 24 per cent in some-

thing over a year. At Newbury the capacity of single-contact b of clinker fell from 19,000 to 10,000 gallons, and that of gravel b from 19,000 to 9,000 gallons in a year's operation. At Hampton i

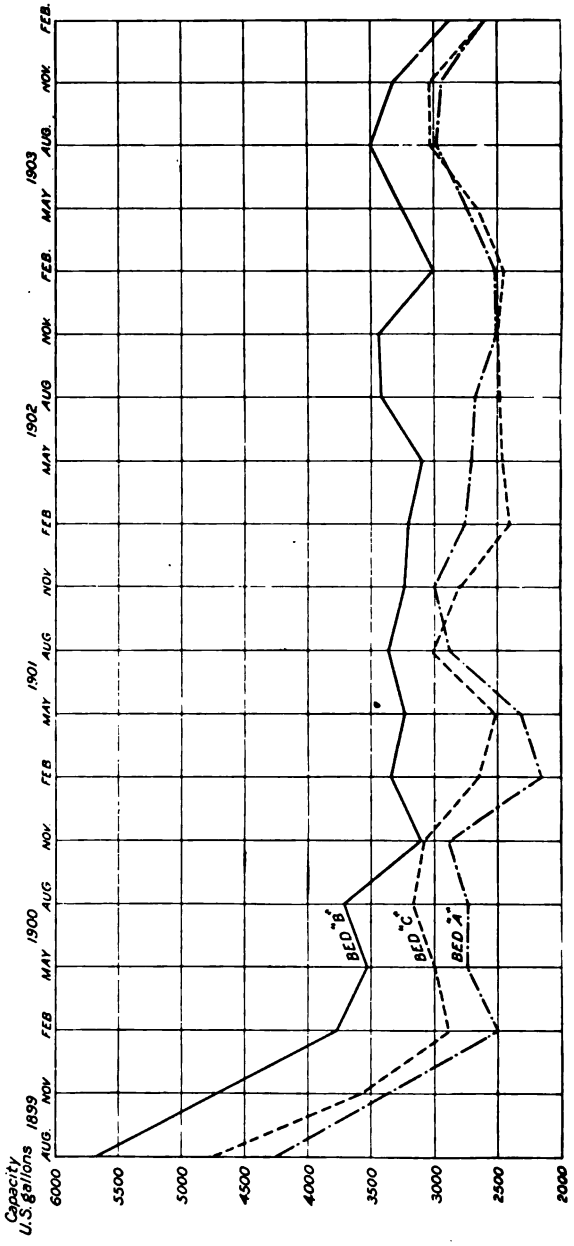


FIG. 6.—Loss in capacity of contact beds at Manchester, England

claimed that coarse beds after more than two years maintain "
original liquid capacity." At Maidstone and Wellington (Some
absence of sludge deposits in the beds was reported (R.S.C., 19(

Experiments in Germany have shown less favorable results as to clogging, perhaps from the use of rather fine material and the treatment of very strong sewages. Dunbar's figures, as given in Table XXVIII, indicate final capacities of only 15 to 20 per cent with material ranging down to one-eighth and three-sixteenths inch. Experiments M, N, O, and P, with three-eighths to 1⅛ inch material, show results substantially like those obtained in England. German practice, however, tends to single contact in beds of fine material. Under such conditions it appeared at Hamburg that the loss in capacity went on in a pretty regular ratio to the amount of applied sewage, the beds soon being so clogged that their capacity fell to 15 or 20 per cent. The average reduction with different materials is shown in Table XXXII. Capacities were not satisfactorily restored by periods of rest.

TABLE XXXII.—*Reduction in capacity of Hamburg filters (Dunbar and Thumm, 1902).*

Material.	Loss in capacity (gallons per million gallons filtered).	Material.	Loss in capacity (gallons per million gallons filtered).
Single contact.		*Second contact.*	
Slag, ⅛- to 3/16-inch	1,330	Slag, ⅛- to 3/16-inch	420
	1,680	Gravel, ⅛- to 3/16-inch	700
Coke, ⅜- to 1½-inch	340	Coke, ⅛- to 3/16-inch	630
Gravel, ⅜- to 1½-inch	280	Slag, ⅜- to 1½-inch	340
Slag, ⅜- to 1½-inch	170	Coke, ⅜- to 1½-inch	360
Brick, ⅜- to 1½-inch	440	Gravel, ⅜- to 1½-inch	460
		Gravel and iron, ⅜- to 1½-inch	650

The German investigators accept this serious clogging with equanimity and suggest the removal and washing of the material when the capacity falls to 20 to 25 per cent. This would be required two or three times a year (Dunbar and Thumm, 1902). The Prussian commission at Berlin came to similar conclusions (Bruch, 1899). Material showed in these experiments a considerably greater capacity after washing than when it was first used. It seems probable that the use of coarser materials, which under proper conditions do not require so frequent removal, is a more economical process. Some of the English filters, for example, have been operated for six years with fair success (Martin, 1905).

Next to the nature and size of filling material the depth of the contact bed is the most important point of general theoretical interest in its construction. Exhaustive experiments were carried out on this point by Clowes and Houston (1904) at London, from which it appeared that beds 3 feet, 5 feet, and 13 feet in depth gave equally good effluents. Studies at Exeter, in which samples were taken from

taps placed at different depths in a contact filter, showed the best results at 3 feet below the surface, and at Manchester a 15-inch bed gave specially good results. At Leeds, on the other hand, 6-foot beds proved better than those of half that depth (R. S. C., 1902 a). Thumm (1902) considers 4½ to 6 feet a maximum depth for one-third to 1 inch material and 1½ to 3 feet a maximum for material under one-eighth inch.

With regard to the operation of contact beds, the number of fillings is the first point to be considered. At Hamburg it was found that for single contact two fillings a day gave the best results, while for double contact six fillings of the primary beds and three fillings of the secondary beds were recommended (Dunbar and Thumm, 1902). In the Barking experiments (Clowes and Houston, 1904) it was shown that two fillings a day gave better results than one; apparently a single filling does not maintain the bacteria at their maximum effectiveness. Birmingham experiments have indicated three fillings a day as effective, to be cut down to two if specially high purification is desired (Watson, 1903). At Crossness it was found that London sewage could be purified with as many as four fillings. At Manchester (1901) also four fillings were recommended.

The distribution of fillings at regular intervals over the twenty-four hours does not appear to be a necessity. At Manchester contact beds were operated for two months with four even six-hour cycles and then for three months with four cycles in ten hours, followed by fourteen hours' rest. The results, as shown in Table XXXIII, were better by the second method.

TABLE XXXIII.—*Results of operation of contact beds at Manchester, England (R. S. C. 1902 b).*

Mode of operation.	Analyses of effluent (parts per million).			
	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—		
		Free ammonia.	Albuminoid ammonia.	Nitrates.
4 cycles in 24 hours	29	16.8	1.5	2
4 cycles in 10 hours	22.3	14.8	1.1	6

The duration of the full period may also vary. Dibdin adopted two hours, and this is perhaps the general English practice. In Germany too, Schumburg and others advocate this period (Bruch, 1899). Harding at Leeds found that one hour gave inferior results, while four hours was no better than two (R. S. C., 1902 a). Roscoe and Cameron, on the other hand, advocate shortening the period to one hour (R. S. C., 1902 a). Frankland found that a value for oxygen consumed of 555 parts per million for raw sewage was reduced to 93 in

'e minutes. It was still 93 after thirty minutes and 49 after twelve ours (Barwise, 1904).

The rate of filtration on contact beds, which is usually expressed ı relation to the superficial area, is of course a function of the depth nd the number of fillings. It would be more reasonable to measure ntact rates in such units as acre-yards, which take account of epth. For uniformity with sand and trickling filters, however, the nit of superficial area is used in this paper. With a bed 3 feet deep nd an open space of 33 per cent, which is a liberal estimate for a atured filter, two fillings a day would equal a rate of 0.65 million llons per acre per day and three fillings a rate of about 1. In prac-e, necessary rests and loss of capacity being taken into account, ree fillings of a 3-foot bed will not amount to a rate of more than 0.8. Barking, in 1898, Clowes and Houston (1904) obtained with one ling rates of 0.6 for coke and 0.5 for ragstone, and in 1899 with two lings the rates were increased only to 0.7. Watson (1903) con-lers 0.4 to 0.6 the best rate attainable, even when the sewage has en previously subjected to septic treatment. Table XXXIV, mpiled from Watson's Birmingham lecture and from the testimony fóre the royal sewage commission, indicates the rates which have en recently obtained in actual operation or in experiment on a actical scale.

TABLE XXXIV.—*Contact-filter rates (Watson, 1903; Martin, 1905).*

Single contact.			Double contact.		
Place	Depth (feet).	Rate (million gallons per acre per day).	Place.	Depth (feet).	Rate (million gallons per acre per day).
anchester	3.3	0.6	Burnley	3	0.3
irmingham	4.5	.6	Leeds	5.5	.6
oydon	3.7	.8	Blackburn	5.5	.8
eter	5	1	Sheffield	3.3	.8
itton	3.5	1	Carlisle	4	1.1
ndon	3	1.2	Sheffield	3.3	1.2
eds	4.5	1.4			

When a double-contact system is used the area must naturally be ıcreased, generally by 50 per cent, the secondary beds being oper-ted at double rate. The discussion of analytical results (pp. 70–71) hows that single contact rarely yields a stable effluent, while double ontact usually does. The fact that, with a given area, better results an be obtained by double treatment at a certain rate than by single reatment at half that rate is made clear by some Manchester experi-nents, the results of which are given in Table XXXV.

TABLE XXXV.—*Results of double and single contact treatment at Manchester (Manchester, 1904 a).*

[Parts per million.]

	Nitrogen as—		
	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.
Septic effluent	25.8	2.5	.....
First contact	14.5	1.2	0.5
Second contact	4.1	.5	8.5
Septic effluent	31	3.5	.....
Single contact (one-half rate)	13.3	1.3	4.3

In the Hamburg experiments it was found that with six d ings in the primary bed and three in the secondary bed as good were obtained by double contact as with two fillings in single-

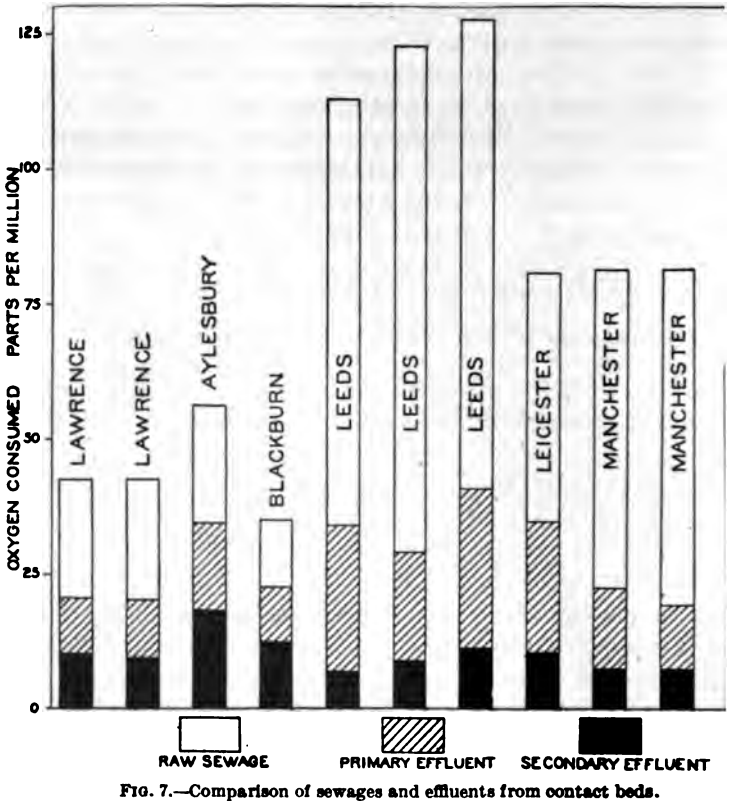


FIG. 7.—Comparison of sewages and effluents from contact beds.

beds. This is shown in Table XXVIII (p. 61), where experi and experiments L and D represent comparable conditions (and Thumm, 1902). It may be noted in passing that in Engla eral practice reverses this relation between primary and sec beds. The Manchester commission suggested that seconda

uld be operated at twice the rate of the primary beds (Manches-, 1900 a).

The purification effected by single and double contact filtration is ly represented by the analyses, collected from various sources, en for comparison in Table XXXVI. The removal of oxygen sumed at the two stages in the process is plotted in fig. 7. It will noted that the first contact removes somewhat more than half of organic constituents of the sewage, as measured by oxygen con-ned and albuminoid ammonia, and two-thirds or more of the sus-ded solids, while the second contact effects almost as great a puri-tion on the first-contact effluent. Aylesbury and Blackburn wed the worst results among the English plants as far as ratio purification is concerned. It will be noticed that these are the kest sewages and in all sewage treatment the last fractions of anic matter are the most difficult to remove. Except at Law-ce the nitrate content of the effluent is rather low, notably at eds and Leicester.

TABLE XXXVI.—*Results of single- and double-contact treatment.*

[Parts per million.]

	Solids.						Nitrogen as—												Oxygen consumed in 4 hours at 80° F.[a]		
	Total.			Suspended.			Free ammonia.			Albuminoid ammonia.			Nitrites.			Nitrates.					
	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.
Lawrence:[b]																					
Nos. 137-163							36.3	24.3	12	5.9	2.4	1.4					8.3	14.6	42.6	21.2	10.3
Nos. 137-164							36.3	24.2	8.6	5.9	2.4	1.2					8.3	21.7	42.6	20.4	9.4
Aylesbury[c]	1,190	1,020	920	367	112	0	56.4	42.7	23.6	6.5	4	1.9		0.3	0.9		.6	13.3	57.5	35.1	18.4
Blackburn[d]	1,080	602	596	474	60	3	23.3	17.3	11.4	2.8	1.7	1		.1	.2		.4	1.1	35.8	23	12.6
Leeds:[e]																					
Nos. 1 and 2	1,670	1,080	980	584	165	27	20.2	12.9	3.7	9.5	3.7	.9						5.6	115	36	7
Nos. 3 and 4	1,690	1,180	1,050	614	180	47	23.8	10.8	6.8	11.3	3.4	1.3						3.7	126	30	9
Nos. 5 and 6	1,780	1,170	1,020	661	196	47	24.1	14.5	7.8	11.8	4.7	1.7						1.8	132	42	11
Leicester[f]	1,320	1,070	1,020	296	73.2	23				10.6	4.2	2.5				0.6	.9	4.6	83.9	33.4	10.7
Manchester:[g]																					
Beds A and D							24	9.1	3.7	3.7	1.4	.6		.4	.2		5.6	10.6	83.9	23.1	7.5
Beds C and D							24	8.5	3.6	3.7	1.3	.6		.3	.2		6.3	10.8	83	19.6	7.5
Sutton[h]	1,630	895	1,000	824	45	5.6	94.2	32.6	8.3	7.3	2.9	1.4		1.5	.7		4.1	19.7	56.9	21.9	9.2

[a] At Lawrence, 2 minutes' boiling.

[b] Lawrence: No. 137-163, run for 18 months during 1901-1902; area of beds, $\frac{1}{200}$ acre each; first contact, broken stone ½ to 1 inch, taking raw sewage, rate 0.9; secondary bed, fine coke, rate 0.7 (Fuller, 1905). No. 137-164, run for 6 months during 1901; like No. 137-163, except that coke was "considerably finer" in secondary bed (Fuller, 1905).

[c] Aylesbury: Experiments during first 6 months of 1898; weekly analyses; no further data given (R. S. C., 1902 a).

[d] Blackburn: No further data (R. S. C., 1902 a).

[e] Leeds: Nos. 1 and 2, experiments during October, 1898, to October, 1899; beds about ½ acre in area; primary contains 5 feet of coke over 3 inches in diameter, receives raw or settled sewage at rate of 0.8; secondary, 6 feet coke, $\frac{1}{16}$ to 1½ inches, rate like primary. Nos. 3 and 4, experiments during November, 1898, to June, 1900: beds each about ½ acre in area and 3 feet deep; primary bed filled with clinker ½ to 1 inch, and secondary $\frac{1}{16}$ to ½ inch; rate during first 6 months, 1.1 (settled sewage), and during remainder of period 0.3 (raw sewage). Nos. 5 and 6, experiments during March to November, 1899; beds each ½ acre in area; primary bed, 3 feet of clinker, 1 to 2 inches; secondary bed, 3 feet of clinker, $\frac{1}{16}$ to ½ inch; rate, 0.8, raw sewage on each bed; 4 hours' contact during a portion of the time (Leeds, 1900).

[f] Leicester: Process No. 14; experiments during November, 1898, to July, 1899; primary beds, $\frac{1}{16}$ acre in area, filled with clinker 1½ to 2½ inches, 4½ feet deep; secondary bed, $\frac{1}{32}$ acre in area, filled with 3 feet of clinker, ⅛ to ½ inch; rate, 1.6 on each bed, septic sewage (Leicester, 1900).

[g] Manchester: Experiments during January 4, 1900, to March 27, 1901; A and C were primary beds, the combined effluents of which were run on to D; area of each bed, $\frac{1}{16}$ acre on the surface; slope inward, 2:1. A contains 3 feet of clinker ⅛ to ⅝ inch; septic sewage at rate of 0.3. C contains 3 feet of clinker ⅛ to ⅝ inch; septic sewage at rate of 0.4. D contains 3 feet of clinker ⅛ to ½ inch; rate, 0.7 (Manchester, 1901).

[h] Sutton: Experiments from October, 1897, to August, 1898; coarse bed 3 feet deep, of burnt ballast; 5 beds of burnt clay; rate in each bed, 1 (R. S. C., 1902 a).

'o these results may be added one more set of analyses to show ıt contact beds have actually accomplished in practical operation ı large scale. At Manchester, in 1903, 28 half-acre primary beds been installed. They were 40 inches deep and filled with one-ıth to 1 inch clinker and were dosed with septic effluent. The ılts of the first year of operation are shown in Table XXXVII.

.E XXXVII.—*Efficiency of primary-contact beds at Manchester, England (Bredtschneider and Thumm, 1904).*

Date.	Rate (million gallons per acre per day).	Analyses (parts per million).					
		Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
				Free ammonia.		Albuminoid ammonia.	
		Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.
1902.							
ary to March	0.46						
l to June	.54	85	34	30	19	4	2.1
to September	.56	80	32	29	17	3.2	1.7
ber to December	.56	89	32	29	16	4	1.6

'he effluent of the first contact process, as is obvious from the ılyses in Table XXXVI, almost always retains too much organic tter to be considered satisfactorily purified. Two successive ıtments, on the other hand, may produce an effluent which is ıputrescible and of good enough quality to be discharged into a ıam. If still better results are desired a third contact may be le. Table XXXVIII shows what may be expected from such a hod. The improvement in successive treatments progressively ens, so that the results obtained are scarcely commensurate with cost. The head required for successive contacts also introduces ırious factor.

TABLE XXXVIII.—*Results of triple-contact treatment.*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Eastry (R. S. C., 1902b)..						
ge	1,550	1,070	25.5	12.8	4.6	123
	1,460	107	22	3	1.9	50.5
	1,340	85.5	12.4	2.4	2.1	25.4
	1,360	21.4	4.8	1.2	7.4	17.2
Leeds (Leeds, 1900).						
ge	1,760	632	27.6	12.4	.....	127
	1,250	274	18.6	7.1	.....	62.4
	1,060	113	13.5	5.1	.....	39.6
	1,030	110	9.7	3.5	2	27.5

t has been shown that the contact bed was developed from the ırmittent sand filter with no idea of changing any other condition

than the rate of operation. It was assumed that the chemical changes were the same in each case. Many English discussions of the process are based on this assumption, and Clark states that at Lawrence the process of nitrification is considered an essential for good purification (Clark, 1903).

Dunbar and Thumm (1902), in a beautiful series of experiments at Hamburg, have shown, however, that the reactions in the contact filter, as a result of the alternate aerobic and anaerobic conditions, follow a peculiar and characteristic course. First, during the reduction phase the solids in the sewage settle on the surface of the filling material and the soluble constituents are to a large extent absorbed by the bacterial jelly with which the material is clothed. This latter phenomenon takes place in virtue of the general tendency exhibited by colloidal films to remove substances from contiguous solutions (Phelps and Farrell, 1905). Dibdin illustrates the removal of suspended matter by analogy with the adhesion of floating chips to larger bodies, and compares the adsorption of dissolved material to the removal of lead acetate by passage through a carbon filter (Dibdin, 1904). The real purification of the adsorbed material has been shown by Dunbar (1905) to be a bacterial process, although Bredtschneider (1905) attempts to maintain its purely mechanical character. During the oxidation phase of full aeration the bacteria set up the ordinary oxidation processes of the intermittent filter, which may be indicated by the following generalized formula:

Reaction 1. Nitrification:

$$\text{(a) } 2R.N:R' + 3O_2 = R.O.R + 2R':O + N_2O_3;)$$
$$\text{(b) } N_2O_3 + O_2 = N_2O_5)$$

At the end of this period considerable quantities of nitrates are present in the filling material of the contact bed, as shown by Dunbar and Thumm (1902). Experiments by Phelps and Farrell (1905) indicate that the amount of nitrates increases with the length of the period. When the bed is refilled for the next cycle the same action continues for a time. Soon, however, the supply of dissolved oxygen is consumed, active nitrification stops, and anaerobic putrefactions begin, causing hydrolytic splittings of the following type:

Reaction 2. Hydrolysis:

$$(R.N:R' + 2H_2O = R.OH + HO.R'.NH_2)$$

At this stage the contact filter has the liquefying properties of the septic tank. There is a bacterial reduction of the nitrates to nitrites, and a formation of partly reduced nitrogenous bodies, primary amines, etc. This leads to a decomposition of the nitrites present and the liberation of gaseous nitrogen according to the following formula:

Reaction 3. Denitrification:

$$2HO.R'.NH_2 + N_2O_3 = 2R'(OH)_2 + 2N_2 + H_2O$$

During the reducing phase the nitrates formed in the empty period are partly or wholly removed. Much of the organic nitrogen originally present is lost as free nitrogen. Clark (1903) has pointed out that this loss amounts to from 38 to 50 per cent and Phelps and Farrell (1905) found a loss of from 35 to 50 per cent. The nitrates found in the final effluent give no true measure of the purification effected, since under ideal conditions the nitrates formed from half the nitrogen would be exactly used up in decomposing the other half. Dunbar and Thumm (1902) found that the highest purification frequently accompanied the lowest nitrate content in the effluent.

The process in the contact bed is evidently an extremely complex one, involving an alternation of anaerobic and aerobic processes. To those who, like most English authorities, believe that putrefaction is an integral part of all sewage purification, such a method must commend itself. Clark (1900) describes a suggestive experiment in which gravel filters were run at a rate of 0.5 with forced upward aeration. Comparing these filters with others operated on the contact plan, he finds that the latter operate for longer periods and at higher rates without clogging and produce better effluents. Nevertheless, in view of recent English work on open filters through which raw sewage is allowed to trickle continuously, and in the light of some of the writers' own experiments, it can not be conceded that the universal necessity for anaerobic treatment has been clearly proved. Even if the need for some such process be granted, its combination with aerobic action in the same filter must be regarded as of doubtful expediency. As Rideal says, "In methods involving a 'resting-full' and 'resting-empty period' there is alternate inversion of bacterial action between aerobes and anaerobes, with a disturbance of both." And again, "In ordinary bacteria beds these reactions are somewhat fortuitously reversed and confused, according to the periods of filling or rest, the fault being caused by mixing all the different bacteria in one or two large filters" (R. S. C., 1902 a). Chemically the decomposition of organic matter into free nitrogen which takes place in the contact bed seems quite ideal. Bacteriologically the combination of two diverse processes must be regarded as theoretically unsound.

Whatever may be thought of the principle of the process, its practical applicability under certain conditions has been thoroughly demonstrated. The results obtained with the famous 1-acre coke bed at Barking and with the double-contact system at Sutton have been amply confirmed. The Barking bed between 1894 and 1901, inclusive, purified 1,500 million gallons of sewage at an average rate of 0.5 for the whole period. The elaborate experiments at Manchester and Leeds showed that even strong industrial wastes could be treated on this principle. At Exeter, Yeovil, Barrhead, Oldham, and Burnley *contact beds* are being regularly operated with success.

That the double-contact process may yield effluents as good as those obtained from sewage farms in actual operation is indicated in Table XXXIX, which presents data obtained by two river conservancy boards in the examination of a number of plants. No distinction has been made as to methods of preliminary treatment. All the contact beds and most of the land areas receive septic or chemical effluent. The Mersey and Irwell standard is 1.4 parts per million of albuminoid ammonia and 14 parts of oxygen consumed. The Ribble standard is 1 part of albuminoid ammonia and 20 parts of oxygen consumed.

TABLE XXXIX.—*Comparison of contact treatment with irrigation and sand filtration, Mersey and Irwell and Ribble watersheds (R. S. C., 1902 b).*

District.	Disposal on—	Number of samples.		Per cent of samples below standard.
		Above standard.	Below standard.	
Mersey and Irwell	Contact beds	8	22	[illegible]
	Land	55	178	[illegible]
Ribble	Contact beds	16	22	[illegible]
	Land	88	207	[illegible]

German investigations have similarly shown at Hamburg (Dunbar and Thumm, 1902), at Berlin (Bruch, 1899), at Stuttgart (Schurr, 1905), and elsewhere that a clear nonputrescible effluent may be obtained by the contact method.

Whether preliminary septic treatment is necessary before contact filtration must be decided by local conditions in the individual case. English opinion strongly inclines to the view that it is generally advisable. The consensus of evidence given before the royal sewage commission indicated that "crude sewage causes so serious a loss of capacity in contact beds as to require preliminary sedimentation and generally septic treatment as well" and that the use of the septic tank "greatly assists the life of the beds by preventing their becoming choked by the accumulation of mineral and indigestible fibrous matters" (Dibdin, 1903). The Leeds experiments certainly showed that the crude sewage of that city could not be treated successfully. At London, Birmingham, and Manchester the conclusion has been reached that septic treatment is desirable. It must be remembered that sludge is produced in the septic tank, the disposal of which must be balanced against the renewal of contact beds. The cleaning of contact beds is of course much more difficult than the emptying of a septic tank. On the other hand, the sludge produced in the beds is probably less in amount and of a less offensive character than that which accumulates in the tank. Furthermore, it has been suggested that septic treatment under certain conditions may interfere with the course of the later biological process. At Hamburg it was found that

while contact beds could handle six doses a day of raw sewage only two doses of septic effluent could be applied, a third dose producing a dark and malodorous effluent (Dunbar and Thumm, 1902). Chemical treatment also interfered with the process, as shown in Table XL.

TABLE XL.—*Results of contact treatment of crude sewage and chemical effluent (Dunbar and Thumm, 1902).*

Precipitant.	Oxygen consumed in 10 minutes' boiling (parts per million).	
	Applied liquid.	Contact effluent.
None	102	27
Lime	69	51
Lime and iron	69	53
Iron	72	19

PURIFICATION OF SEWAGES BY A CONTINUOUS TRICKLING PROCESS OVER COARSE MATERIAL.

At about the same time that the system of contact treatment was worked out the foundations were laid for the development of another method of purification by rapid filtration through coarse material under wholly aerobic conditions. In modern filters of this type the supply of oxygen is maintained and the flow slackened sufficiently to permit purification by applying the sewage in a fine, continuous spray, and the beds are termed sprinkling or trickling filters. The early Lawrence experiments on the filtration of sewage "through clean gravelstones larger than robins' eggs" (Mills, 1890) furnished the first suggestion of such a process. In 1892 Hazen started a filter of one-fifth-inch material which received four doses of sewage a day and was artificially aerated. The rate was increased from 0.14 at the start to 0.48. The surface clogged badly, but the effluent was good, showing 30 parts per million of nitrates. In 1892 Lowcock, at Malvern, England, constructed a gravel filter with a sand layer on its surface and filtered chemical effluent at a rate of nearly 0.3 million gallons per acre per day, forcing air under pressure into the middle layer of the bed. A good effluent was obtained and the filter was operated for fifty-one days without rest (Lowcock, 1894). Similar filters were later constructed at Wolverhampton and at Tipton (Rideal, 1901). At both places ordinary trickling filters have since been installed (R. S. C., 1902 a). In the United States Waring was attempting at the same time to use the principle of forced aeration. He obtained a patent on his process as early as 1891 and carried out a series of experiments at Newport in 1894 on "the mechanical straining out of all solid matters carried in suspension in sewage and their subsequent destruction by forced aeration and the purification of the clarified sewage by bacterial

oxidation of its dissolved organic matter in an artificially aerated filter." Straining through broken stone removed 40 per cent of the nitrogenous matter in the sewage, and it was concluded that "if the thick sludge is removed and the upper 6 inches of the filtering bed opened up by raking or plowing after the filter is drained an aeration period not exceeding five days is sufficient to quite restore the strainer to its original efficiency." Waring says further that "the sewage, instead of passing through the filter in a solid column, as in the former case, trickles down in a thin film over the surfaces of the particles of coke or other filtering material, while through the voids between the particles and in immediate contact with the trickling films of liquid a current of air is constantly rising, being introduced at the bottom of the tank by a blower." It is stated in the report of these experiments that the aerators removed "over 95 per cent of the organic nitrogen of a strainer effluent applied at a rate of at least 800,000 gallons per acre per day" (Waring, 1895).

Waring's principle of oxidation was undoubtedly correct; but the method of forced aeration is of more doubtful expediency. For the complete oxidation of various organic compounds Dibdin (1903) calculates that an amount of oxygen equal to from two to four times the weight of their total carbon would be required. This means with an average sewage a supply of 5 to 10 liters of air to a liter of sewage. The difficulty of maintaining such a supply of air by forced aeration is manifest, and the plants actually installed on the Waring plan have not generally operated with marked success. The best example of the process is that at East Cleveland. Here the beds speedily clogged when treating raw sewage, although since the installation of a septic tank for preliminary treatment they have worked better. The engineer of the Ohio State board of health says of this plant: "When visited in winter the surfaces of the aerators were frozen and they were out of service, the sewage being passed through septic tanks and primary and secondary filters only. It is said to be practically impossible to clean the surface of the aerators during cold weather, but on account of the rapid rate of filtration these filters rapidly accumulate solid matter on their surfaces and need frequent cleaning" (Pratt, 1905).

A practically successful solution of the problem of aeration has been reached along another line, and depends on the supply of sewage, continuously or at very frequent intervals, in small amounts distributed evenly over the whole area of a filter. Under such conditions the sewage trickles in thin films over the surface of the filling material, while the spaces between are continually filled with air, the oxygen content of which in practice does not become seriously exhausted (R. S. C., 1902 a). The air supply under the best conditions may amount to five times the volume of sewage. The material over which films of sewage continuously trickle supports an

growth of micro-organisms. The condition is analogous to the ation of acetic-acid bacteria in the process of vinegar manufac- y the flow of alcoholic liquor over shavings. The complica- introduced by "a series of compensating errors of surfeiting arvation" are exchanged for a simple and constant condition. the name of the trickling filter, the percolating filter, the mittent continuous" filter, the sprinkling filter, etc., this proc- s come nearer than any other to realizing the ideal conditions oid purification.

first description of a method for sewage treatment based on an of trickling over coarse material with natural aeration was hed by Stoddart in 1893. In the next year the same inves- r exhibited a model at the Bristol meeting of the British Med- ssociation in which sewage and other liquids were discharged ps over a filter of coarse chalk. A solution of ammonium te containing 140 parts per million of nitrogen was almost tly nitrified at a rate of 11.6 million gallons per acre per day. e was completely nitrified at a rate of 1.2 and well purified (Dibdin, 1903). Nitrification was found to increase with the of the filter. The first working filter actually constructed by art was installed at Horfield in 1899. Its efficiency under vari- nditions of flow is indicated in Table XLI.

LI.—*Results of purification by Stoddart trickling filter at Horfield, England (R. S. C., 1902 a).*

nditions.	Rate (million gallons per acre per day).	Material.	Analyses (parts per million).				
			Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	Suspended solids.
			Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.		
nally strong	3.4	Sewage	426	113	0	330	.....
		Septic effluent	119	9.1	0	50	.....
		Trickling effluent	74.2	3.1	21.4	21	.....
her flow	8.2	Sewage	80.5	10.7	0	77	300
		Septic effluent	31.8	3.8	0	17.4	45.6
		Trickling effluent	15.2	1.1	25.7	7	0
ther flow	10.5	do	1.6	.4	18.1	.....	0

same principle was independently worked out by Corbett, rough engineer of Salford, in a series of experiments begun 3 under the inspiration of the work of the Massachusetts board of health. He first used wooden troughs for distribu- nd later fixed sprinklers, obtaining excellent results in the case. Ducat, another pioneer in the development of the ng filter, urged the importance of thorough aeration, building with open sides to attain that end, and maintained that the c process alone was entirely competent for the treatment of sewage. He installed a small filter at Hendon in 1897.

Finally, in connection with the development of this process, should be mentioned Scott-Moncrieff, who carried its principles to a logica extreme in a series of experiments at Ashtead in 1898. He believe that several different types of organisms were concerned in the pur fying process and that their separate and successive cultivatic under perfect aerobic conditions would give the most favorab results. He therefore constructed a series of nine trays of 1-in coke, each 2 by 7 feet by 7 inches deep, arranged one over t other, with a space of 2 inches between each pair. The efflue from a "cultivation tank" was discharged on the upper tray by tipping bucket at a rate of 1.3 million gallons per acre per day (0. on the whole area of nine trays), and its passage through the seri occupied from eight to ten minutes. The degree of purificati attained, as indicated in Table XLII, was extraordinarily high.

TABLE XLII.—*Results of trickling filtration through Scott-Moncrieff's trays (Scott-Moncri 1899).*

[Parts per million.]

Effluents of—	Nitrogen as—				Oxyge consum in 4 hou at 80° I
	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.	
Cultivation tank	103	12.3	0	1.2	9
First tray	86.5	10.3	9.9	1	6
Second tray	74.2	8.2	9	4.8	5
Third tray	41.2	4.9	7.8	18.7	4
Fourth tray	33	2.9	6.6	27.6	1
Fifth tray	12.4	1.2	4.8	46.8	1
Sixth tray	14.4	2.9	5.1	44.2	1
Seventh tray	2.9	2.5	0	66	
Eighth tray	1.7	5.3	0	73.2	
Ninth tray	2.1	4.9	Slight tr.	90	

A plant of this type has been installed at Caterham Barrack where it handles daily 16,000 gallons of very strong sewage at rate of 0.4. Oxygen consumed is reduced from 92 to 27 parts p million, free ammonia from 149 to 50 parts, and organic nitroge from 27 to 7 parts, with a formation of 90 parts of nitric nitroge (Rideal, 1901). The German commission on its visit to England i 1902 reported that the effluent from this plant was stable, althoug it contained 68 parts per million of nitrogen as free ammonia, 5. parts of organic nitrogen, and 51 parts of oxygen consumed (Bred schneider and Thumm, 1904).

It is not clear that there is any such complex division of lab between various classes of nitrifiers as Scott-Moncrieff postulate Whether any important advantage is to be gained by dividing trickling filter into layers with air spaces between has never bee definitely determined. At Salford Corbett found no gain from divi ing his filters into three or four successive heights of 20 inches ea (Rideal, 1901).

The general practice is to construct trickling filters in single beds, hich are merely heaps of the selected filtering material. It is not ecessary that such a filter should be tight as long as its bottom is uilt with sufficient slope to carry off the effluent. It is desirable at it should be underdrained in some way in order to avoid clogging d to maintain a good air supply, passing upward, chimney fashion, rough the filter. In some cases tile drains are so arranged as to rm practically a false floor. The walls of the Ducat filter are built open drain pipe inclined upward and connected with aerating ains at intervals in the body of the bed. The Whittaker-Bryant ters at Accrington and elsewhere are octagonal in shape, with walls open brick and central open-brickwork aerating wells. Both these pes are costly (Kinnicutt, 1902). Filters may be constructed more mply by merely surrounding the filtering material with a fence of pright palings. The Stoddart filter is a heap of coke or cinders of is sort on a sloping floor without any walls. The two quarter-acre ickling beds now in operation at Birmingham are essentially of this pe (Watson, 1903). The oldest of these beds was built of slag aded upward from one-half inch to three-fourths inch, heaped up ithout underdrains, the outside being held together by iron bands. ore recent filters are of one-half to 3 inch broken brick underdrained y a false floor of tiles.

The most difficult point in the construction and operation of the ickling filter is the distribution of the sewage over its surface. The eal condition for aeration would be the discharge of sewage in a fine d even spray over the whole surface of the filter. On the other nd, there is some evidence that a too regular distribution favors ien growths, which clog the surface of the filter. Scott-Moncrieff d Ducat originally used tipping buckets and troughs placed at tervals over the filter, relying on the dash to distribute over intere diate areas. This plan has been tried at Hendon and Leeds. At e other extreme in principle is the Stoddart distributer as used at orfield. It is practically a series of channels, over the sides of hich the sewage overflows continuously, dripping from a series of oints on the under side, 360 points being allowed to a square yard. heoretically this should secure a very even distribution; but such hannels are liable to buckle and it is difficult to keep them level. urthermore, they are liable to clogging from fungous growth (Barise, 1904). A more practical method than either the tipping bucket r the Stoddart drip distributor is the method of distribution under ressure through perforated pipes. This was developed at Salford fter various other attempts with troughs and with a thin layer of and laid over the surface of the main filter. Disk-like caps were laced over the openings of the pipes in some early experiments in rder to secure a good spray for distribution. Then the attempt was

made to get a spray by the impact of two converging flows, and finally a special form of opening was designed to give a rotating movement to the stream. This system is in use on the new filters at Birmingham and works well when good pressure is available (Baker, 1904). Barwise (R. S. C., 1902 a) describes the use in Derbyshire of fixed perforated pipes with metal disks placed over the outlets for spraying, dosed intermittently by automatic flush tanks. The same principle is used at Chesterfield. At Accrington intermittently operated fixed sprinkler pipes gave poor results in some preliminary experiments (Bredtschneider and Thumm, 1904).

Many plants in England are equipped with still more complex revolving sprinklers operated either by the pressure of their own jets or by mechanical power. The Candy-Whittaker sprinklers at Accrington are of the former type. With this filter, as well as with that of Ducat at Leeds, it was thought that it would be of advantage to warm the sewage before applying it, and the temperature was raised about 4° by the steam of the pulsometer used for pumping. The heating seems of little advantage, and at Leeds was found actually harmful, since it promoted surface growths which tended to clog the filter. All revolving sprinklers require much attention to keep them in operation and are subject to grave derangement from weather conditions. Daily cleaning with brushes is necessary with many plants to prevent serious clogging of the openings. Even more elaborate than the ordinary revolving sprinklers is the Scott-Moncrieff distributor installed at Birmingham, in which a radial trough revolves about an axis at the center of the bed, its outer end resting on a moving wheel, sewage running in a thin film over a weir which extends for the length of the trough.

With regard to depth and material in trickling filters there may be considerable latitude. In a series of experiments at Salford, analyses from which are quoted in Table XLIII, no better results were obtained with an 8-foot filter than with one only 5 feet deep.

TABLE XLIII.—*Efficiency of trickling filters of different depths at Salford, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Suspended solids.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—	
			Free ammonia.	Albuminoid ammonia.
Raw sewage	280	58	19.8	5.1
Chemical effluent	40	42	16.5	4.5
Roughing filter	20	40	16.5	4.3
Trickling filter effluent (5-foot)	0	6.5	5.3	2.1
Trickling filter effluent (8-foot)	0	5.5	4.9	1.

Bell testified in 1902, apparently with regard to the same filter that the oxygen-consumed value for the 8-foot filter was 12, again

for the 5-foot bed. He considered this difference too little to pay the increased depth (R. S. C., 1902 a). Whittaker, on the other ıd, reports much better results with beds 9 feet deep than with a ›th of 4 feet 8 inches (R. S. C., 1902 a). Probably 4 feet is the est minimum, and greater depths are desirable because of the dan- · in shallow filters that streams of unpurified sewage may pass ·ough channels, due to irregular packing of the material. Ducat ommended a depth of 5 feet when the effluent was to be dis- ırged into brackish water, 8 feet for discharge into rivers, and 10 t for small streams. The period of flow through trickling beds ries, at Leeds, from two or three minutes with very coarse beds up thirty minutes with fine material.

It is probable that there is a maximum amount of organic matter sent in sewage which can be easily nitrified by the trickling process, d that additional action does not produce results commensurate th the cost of deep single filters or of double and triple beds. Thus Leeds it was found that the rate of improvement in the effluent of ee successive beds rapidly decreased, as shown in Table XLIV.

TABLE XLIV.—*Efficiency of trickling filters at Leeds, England (Dibdin, 1903).*

[Parts per million.]

	Total solids.	Suspended solids.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
			Free ammonia.	Albuminoid ammonia.	
age	1,760	631	27.6	12.2	127
ent No. 1	1,250	275	18.5	7	62.5
ent No. 2	1,060	113	13.3	5	39.6
ent No. 3	1,010	110	9.7	3.5	27.6

With regard to the best material for the construction of trickling ters, data have been collected in a number of the English experi- ents. At Salford slag was found somewhat better than polarite, avel, coke, or clay (Bredtschneider and Thumm, 1904). At York well-controlled series of investigations indicated, as shown in Table LV, that coke and boiler slag (clinker) are slightly better than brick nd blast-furnace slag.

ABLE XLV.—*Efficiency of trickling filters of different material at York, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Albuminoid ammonia.	Nitrates.	
Raw sewage	13.9	0	82.9
Broken-brick effluent	1.4	18.4	10
Blast-furnace slag effluent	1.2	18.8	9.6
Coke effluent	.9	23	7.1
Boiler-slag (clinker) effluent	1	22	6.9

Coal has been found especially favorable to the process. At ton the effluents from destructor breeze and coke showed, re tively, 0.8 and 0.9 parts per million of albuminoid ammonia an and 0.7 parts of nitrates, while a coal filter yielded only 0.4 pa albuminoid ammonia and 3.4 parts of nitrates (Barwise, 1 Striking differences obtained at Tipton are shown in Table XLV

TABLE XLVI.—*Efficiency of trickling filters of various types at Tipton, England (B 1904).*

[Parts per million.]

	Solids.		Nitrogen as—			O co in at
	In solution.	In suspension.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Tank effluent	827	16	10.3	1.9	0	
Coke-breeze effluent	840	9	7.4	1.3	3.8	
Lowcock's filter effluent	807	14	2.2	.4	7.4	
Garfield's coal-filter effluent	914	3	1.6	.3	8.1	

On the whole, it seems probable that any hard, smooth ma will serve well for the trickling filter. Coal is perhaps most pr ing, but granite, flints, gravel, and hard clinker are all suitable.

The size of material used may also be varied considerably w certain limits. The elaborate experiments carried out by Re Hanley, cited in Table XLVII, indicated that fragments from t sixteenths inch up to 1½ inches yielded almost identical results (ley, 1904). Barwise (1904) suggests one-eighth to one-half material. Among the witnesses before the royal sewage comm Garfield recommended one-sixteenth to three-sixteenths inch, I one-eighth to one-half inch, Corbett three-sixteenths to three-fo inch, Candy three-sixteenths to one-half inch for fine and t fourths inch to 3 inches for coarse beds, Harding one-fourth in 1½ inches for fine and over 3 inches for coarse beds, Whittaker 1 to 1½ inches, and Stoddart 2 to 3 inches.

TABLE XLVII.—*Efficiency of trickling filters with material of various sizes at Hanle land (Hanley, 1904; Wilcox and Reid, 1904).*

	Size of material. (inches).	Analyses (parts per million).					O co in at
		Solids.		Nitrogen as—			
		Dissolved.	Suspended.	Free ammonia.	Organic.	Nitrates.	
Sewage	.....	1,250	629	17.3	6.3	0	
Septic tank	.....	1,050	44	15	2.2	0	
Rectangular bed:							
Section 1	3/16 to ⅛	1,120	4	.7	.2	17.5	
Section 2	½ to ⅛	1,120	3	.8	.3	17.3	
Circular bed:							
Section 1	3/16 to ⅛	1,120	2	.8	.2	16.6	
Section 2	½ to ⅛	1,130	14	.3	.2	15.3	
Section 3	½ to ½	1,130	7	.3	.2	16.2	
Section 4	1½ to ½	1,130	17	1	.4	16.2	

The rate at which trickling filters may be operated seems gen to lie between 1 and 3 million gallons per acre per day. Duca

Moncrieff recommend a rate of 1.2; Barwise suggests 1.5; Watves the figures quoted in Table XLVIII for current English e. Still higher figures may be attained at times. At Salford e, at first 3, was raised to 6 without injuring the quality of the t (Bredtschneider and Thumm, 1904).

TABLE XLVIII.—*Depth and rates of trickling filters (Watson, 1903).*

Place.	Depth (feet).	Rate (million gallons per acre per day).
.....	9	1.2
n.....	8.5	2.3
am.....	5	1.2
.....	9	2.6
.....	6.5	2.6
.....	9	2.3

analytical results produced by a number of English trickling are brought together in Table XLIX. It will be noticed that cess here is a true nitrification, producing considerable amounts ate in the effluent. The purification is good, distinctly higher eral than that obtained by the double-contact process. The as measured by oxygen consumed are plotted in fig. 8. The ng effluents are in general better than those yielded by contact r sewage farms, if not quite equal to those produced in intert filtration.

TABLE XLIX.—*Efficiency of trickling filtration.*

[Parts per million.]

Place.	Material.	Solids.		Nitrogen as—				Oxygen consumed in 4 hours at 80° F.
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites and nitrates.	
n[a]	Sewage.....	.....	.....	.....	4.6	.....	0	49.9
	Effluent.....	.....	.....	.....	1.5	.....	23.3	18.1
.....	Sewage.....	.....	.....	71.6	13.2	.....	.....	147
	Effluent.....	.....	.....	2.5	.8	.....	4.8	7.8
.....	Sewage.....	.....	.....	39.5	16.5	.....	.....	14
	Effluent.....	.....	.....	5.1	1.6	12	13.7	16.3
.....	Sewage.....	1,120	187	21.2	5.1	.....	.....	57.5
	Effluent.....	1,000	80	8.1	[d] 1.3	7.8	.....	[d] 9.8
.....	Sewage.....	1,110	229	21.7	5.4	.....	.....	59.7
	Effluent.....	1,010	110	6.2	[d] .9	9.6	.....	[d] 8.4
.....	Sewage.....	1,850	768	33.9	12.8	.....	.....	114
	Effluent.....	1,020	0	11.7	1.4	4.5	.....	[d] 10.1
.....	Sewage.....	1,820	850	32.8	12.6	.....	.....	141
	Effluent.....	986	Trace.	1.9	.5	12.1	.....	[d] 3.4
.....	Sewage.....	1,470	486	23.5	9.4	.....	.....	116
	Effluent.....	979	81	3.2	1.3	6.2	.....	12.1
mpton[f].....	Sewage.....	.....	.....	47.1	3.3	1.4	.....	43.3
	Effluent.....	.....	.....	23.8	.6	16.4	.....	3.6
.....	Sewage.....	840	.....	31.8	5.9	0	.....	42
	Effluent.....	719	.....	2.1	.6	113	.....	6.6

al aerobic filter, September 19 to October 19, 1898, receiving septic effluent (Rideal, 1901).
filter, October 14, 1898, receiving crude sewage; single analysis (Rideal, 1901).
aker bed No. 1, March 9, 1899, to May 8, 1900, receiving septic effluent (Martin, 1905).
sis made of the rough settling of suspended solids.
aker bed No. 2, September 2, 1899, to January 30, 1900, receiving septic effluent (Martin, 1905).
filter, March 29 to April 30, 1900, receiving crude sewage (Martin, 1905).
filter, June 13 to July 7, 1900, receiving crude sewage (Martin, 1905).
filter, December 13, 1900, to January 14, 1901, receiving crude sewage (Martin, 1905).
lter, January 1896, to September, 1898, receiving chemical effluent (R. S. C., 1902a).
effluent.

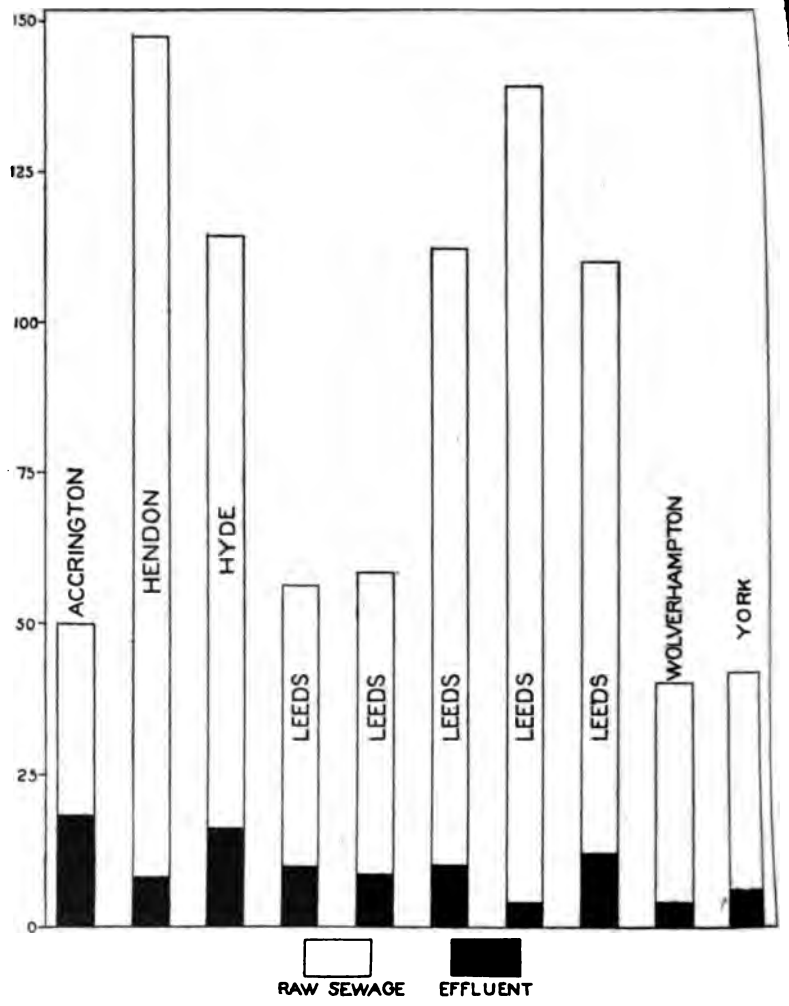


FIG. 8.—Comparison of sewages and effluents from trickling beds, showing oxygen consumed, in pa per million.

Barwise (1904) gives a number of analyses of effluents coveri shorter periods, which are summarized in Table L.

TABLE L.—*Analyses of trickling-filter effluents (Barwise, 1904).*

Place.	Rate (million gallons per acre per day).	Analyses (parts per million).		
		Nitrogen as—		Oxyg consun in 4 ho at 80°
		Albuminoid ammonia.	Nitrates.	
Chesterfield	0.5	0.6	19.3	.....
Burton	.5	.4	8.7	.....
Langwith	1	.2	4	
Chesterfield Borough	1	.5	18	
Long Eaton	1	.7	6	
Buxton	1	.2	2.5	
Dronfield	1	.2	13	

The effluent of the trickling filter contains, as a rule, a certain amount of flocculent organic matter which mars its appearance, but this matter has been more or less completely oxidized and is of a stable, humus-like character. The effluents look worse and keep better than would be expected from their analyses. Clark has brought out this difference in a series of experiments summarized in Table LI. In each case the effluent was allowed to stand in a stoppered bottle in the laboratory, samples being withdrawn at intervals. To judge by free ammonia and oxygen consumed, both contact effluents were, at the start better than those from the trickling filters. It was evident, however that—

> The large amount of residual organic matter in the effluents of filters Nos. 135 and 136 had been, owing to the aerobic conditions prevailing in these filters, as evidenced by the high nitrates in the effluents, so changed by the bacteria and air that it was in a fairly stable condition. The effluents of these two filters—Nos. 135 and 136—contained dissolved oxygen; at the end of the period of experiment, notwithstanding the large amount of organic matter present, no putrefaction took place, odors did not develop, and the organic matter present remained practically without change. The effluents of filters Nos. 137 and 163 contained less organic matter than the effluents of filters Nos. 135 and 136, but were, nevertheless, in a much lower state of nitrification; dissolved oxygen either was not present or disappeared quickly, and putrefaction occurred. Instead of the amount of nitrogen present as free ammonia remaining constant, as in the effluents of filters Nos. 135 and 136, it increased. The amount of oxygen consumed, instead of decreasing, increased eventually in the effluent of filter No. 137, and the anaerobic actions in the bottles containing this effluent and the formation of gas were quite noticeable, odors developing also. [Clark, 1902.]

The suspended solids may be easily removed from the trickling effluent by a short sedimentation. When so separated they are sometimes in themselves putrescible (R. S. C., 1902 a), but usually show only a small proportion of unstable matter. At Leeds (1900) analyses of the dried sediment from a trickling-filter effluent showed the following composition: Organic matter, 31 per cent; mineral matter insoluble in acids, 19 per cent; other mineral matter, 19 per cent. The clear liquid and the suspension which comes fresh from the trickling filter are stable when the bed is operating properly.

TABLE LI.—*Comparative stability of stored effluents from contact and trickling filters (Clark 1902).*

TRICKLING FILTER NO. 135.

Time elapsed (days).	Nitrogen as					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
0	20.1	2.3	1	51.8	0.1	24.4	34.[illegible]
7	18.2	2.2	.8	44.2	6	19.5	15.[illegible]
14	19.4	1.9	.7	49.1	1.1	20.9	9.[illegible]
21	19.4	2.1	.8	46.2	1.3	21.5	13.[illegible]
28	20.1	2	7	39.4	2	21.3	7.[illegible]

TABLE LI.—*Comparative stability of stored effluents from contact and trickling filters* (*Clark, 1902*)—Continued.

Time elapsed (days).	Nitrogen as—					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
TRICKLING FILTER NO. 136.							
0	13.2	2.4	1.1	52.8	0.1	25.6	[illegible]
7	13.2	2.1	.7	50.8	1.1	19.4	[illegible]
14	13.2	1.9	.6	49.7	.5	18.3	5
21	13.2	1.8	.6	47.3	.2	17.1	1.0
28	13.5	1.9	.6	44	0	18.4	.3
CONTACT FILTER NO. 137.							
0	21.4	2	1.4	6.2	0.2	17.4	0
7	23.1	1.8	1.1	.1	0	22.8	0
14	23.9	1.6	.8	.1	0	24.8	0
21	26.4	1.4	.8	.1	0	23.2	0
28	26.4	1.3	.9	.1	0	23.2	0
CONTACT FILTER NO. 163.							
0	14.8	1.6	1	14.9	0.1	11.8	[illegible]
7	14.8	1.3	.6	6.6	0	10.8	0
14	15.1	1.1	.6	5.3	0	10	0
21	16.2	1	.6	1.6	0	9.4	0
28	17.4	.9	.4	2.5	.2	8.6	0

The trickling filter comes into direct competition with the double-contact system of sewage treatment, and it is necessary in every individual case to determine which of the two methods is most suitable. A comparison of the general features of the methods indicates that "on the whole the advantage rests with percolating filters" (Barwise, 1904). It has been pointed out (p. 73) that the trickling filter is simpler in theory, since it depends on the uninterrupted maintenance of a single process of aerobic oxidation. The construction of the body of the bed is cheaper, since the trickling filter need not be made tight and can be built entirely without walls. In operation the advantage probably rests with the contact bed, since the methods of distribution on the trickling filter, as so far developed, are expensive when working well and are liable to get out of order. Since, in principle, the operation of the trickling filter is simplicity itself, it seems that the mechanical difficulties involved should not be insuperable. The operation of trickling filters under severe climatic conditions apparently does not present serious difficulties. At Leeds winter weather produced no derangement of beds or distributors. In America the problem is somewhat more serious. The spray filters at the Columbus experiment station appeared to the casual observer (Winslow, 1905) to be working well in the severe winter of 1904–5; but it is certain that many of the complicated English distributors could never be operated in this climate.

With regard to rate and its converse, required area, the advantage all on the side of the trickling filter. Double-contact beds 6 feet eep can not be operated at a rate over 0.5 million gallons per acre per ay (calculated on the combined area of the two beds). With trick-ng filters, on the other hand, a rate three or four times as high may ily be attained. It was estimated at Leeds that 17 acres of trick-ng filters could be substituted for 165 acres of double-contact beds. ith regard to the results produced, it must be concluded that the ickling effluent is generally superior to that of the double-contact d. It is more turbid, but contains less organic matter and shows eater stability. Finally, the trickling filter is apparently not sub-ct to so serious clogging as the contact bed. What little clogging curs does not interfere with the capacity of the beds. Further-ore, deposits may easily be washed out of the filter, and this washing to a great extent accomplished automatically at times of storm. It ems even possible that in some cases crude sewage may be handled the trickling filter. Harding says:

n the case of Leeds, I must say I do not see that there is any necessity for antecedent tic action, and if it proves practicable, as I think it will, to devise an automatic screening aratus to take off the grosser solids, I think it would be possible to put crude sewage h finely divided solids direct upon a continuous filter and then have a settling tank at the of the process, instead of at the beginning, or if the land is available, as it would be bably for the Leeds works, pass it overland for the purpose of mechanically separating—ring—the suspended solids. [R. S. C., 1902 a.]

As evidence against the trickling process it should be noted that Belfast Letts obtained very poor results with the trickling filter en filtering septic effluent. He used the Stoddart distributer, and bed was 3 feet 9 inches deep, filled with 6-inch clinker. The puri-ation was less than that obtained in parallel experiments at lower tes with a single-contact bed (Martin, 1905). The large size of e material used and the poor distribution seem to have vitiated this periment. At Manchester a Stoddart filter of coarse clinker 2 to inches, dosed with septic effluent, was tested in 1900. The effluents ere of fair quality, but so turbid as to require settling (Manchester, 01). Again, in 1902 a desultory experiment was made by dosing second-contact bed with a sprinkler and leaving the outlet open. he secondary bed received six fillings a day, each occupying about hour, so that it worked as a sort of trickling filter for a quarter of e time. A comparison of the effluent obtained in this way with at from the secondary bed operated as a contact bed showed that e latter process gave distinctly better results.

It should be mentioned that several determinations which have been made show that ere is more dissolved oxygen in the filtrate from bed D when this bed is worked continu-sly than when it is worked as a contact bed; there is, however, invariably more suspended atter in the former case. It is no doubt owing to this suspended matter that the percent-e purification results above given are unfavorable to the sprinkler. [Manchester, 1903.]

With the exception of these incomplete and inconclusive studies, the evidence of comparative tests favors the trickling process. At Leeds the matter was studied most exhaustively. The analytical results, as indicated by the figures quoted in Tables XXXVI and XLIX, were slightly better for the trickling process than for the contact beds, with rates threefold higher. While contact beds clogged badly even with septic effluent, the trickling beds, if built of coarse material (over 1½ inches), maintained their efficiency (Leeds, 1900). At York an elaborate series of comparative experiments was carried out in 1899 and indicated a marked superiority for the trickling filter (York, 1901). The principal analytical results are summarized in Table LII.

TABLE LII.—*Results of experiments at Naburn disposal works, York (York, 1901).*

Conditions.	Material.	Rate (million gallons per acre per day).	Analyses (parts per million).				
			Total solids.	Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
				Free ammonia.	Albuminoid ammonia.	Nitrates.	
Closed septic tank and single-contact filters, August, 1899, to September, 1901	Sewage	0.5	872	33.6	5.1	.....	31
	Effluent	.....	571	19.7	1.8	.....	11
Crude-sewage and double-contact beds, August to October, 1899	Sewage	.2	819	38	4.2	.....	33
	Effluent	.....	711	9.8	1.2	8.3	6.3
Ladder filter, August to November, 1899	Sewage	.4	897	38	4	0	33
	Effluent	.....	950	25	2.5	0	18
Open septic tank and continuous filter, July, 1900, to August, 1901	Sewage	2.6	840	31.8	5.9	.....	42
	Effluent	.....	719	2.1	.6	113	6.6
Open septic tanks and double-contact beds, November, 1900, to August, 1901	Sewage	.2	876	24.7	6.3	.....	42
	Effluent	.....	645	4.6	.8	27.6	9.1

At Accrington trickling filters have been substituted for contact beds (Baker, 1904); and the same change is contemplated at Heywood (Bredtschneider and Thumm, 1904).

RECENT TENDENCIES IN SEWAGE-DISPOSAL PRACTICE IN ENGLAND, GERMANY, AND THE UNITED STATES.

Advances in the art of sewage disposal by processes of rapid treatment have been made almost wholly in England. It is natural that such should have been the case, since the concentration of population in that country renders some method of treatment necessary and since the lack of sandy soil makes the method of intermittent filtration impracticable. We have seen that the first steps were taken by Dibdin in the London and Sutton experiments of 1892-1896, which proved that the contact bed was capable of successfully treating sewage at high rates. Meanwhile Cameron's septic tank, installed at Exeter in 1896, was demonstrating the anaerobic process of preliminary treatment. At both Sutton and Exeter septic tanks

ed by contact beds have since been installed (Baker, 1904). ondon the system of chemical precipitation remains essentially vas in 1892. The experiments carried out by Clowes and Hous- 1898–1901 led, however, to the recommendation that instead s process there be substituted (*a*) sedimentation of mineral mat-) septic treatment in tanks of six hours' capacity, and (*c*) treat- in single-contact beds of coke 6 feet deep (Clowes and Houston,

next important series of investigations was that carried out nchester. This city, the third metropolis of England, has a ation of half a million and a daily flow of 42 million gallons of industrial sewage. Chemical precipitation was introduced in but the effluent created a nuisance in the ship canal into which discharged. No land was available for treatment, and in 1898 mission consisting of Baldwin Latham, Percy Frankland, and . Perkins began a series of experiments on the newer rapid ds. The first report, made in 1899 (Manchester, 1900 a), con- l that in spite of the presence of industrial wastes, the "bac- system is the system best adapted for the purification of the e of Manchester." The experts believed that double-contact vould produce a satisfactory effluent. "It may be taken broadly n the first contact 50 per cent of the dissolved impurity is re- l and that in the second contact 50 per cent of the impurity emaining in the effluent is disposed of." They held that "in that a bacterial contact bed may exercise its full powers of ation, it is necessary (*a*) that it should be allowed sufficiently nt and prolonged periods of rest; (*b*) that the sewage applied should, as far as possible, be free from suspended matters; (*c*) he sewage applied to it should be of as uniform a character as le." They therefore recommended the installation of open tanks and double-contact beds. The secondary beds have not en constructed, but 46 acres of primary beds were in operation 4 (Baker, 1904).

next important investigations were carried out at another manufacturing center, Leeds. Here some experiments were in 1870 which led to the adoption of chemical precipitation. 94 a special commission recommended broad irrigation, but ent land was not available. In 1897 investigations were begun Hewson, W. H. Harrison, and T. W. Harding, and reports have nade in 1898, 1900, and 1905. It was found that the double- t process gave good results with crude sewage and excellent with septic effluent, but that serious difficulty was experi- in maintaining the capacity of the primary beds. Trickling of fine material gave good results, but clogged badly.

On the other hand, continuous filtration over very coarse material of septic effluent and even of crude sewage has given interesting and remarkable results if the solids in suspension which come out in the effluent are settled after filtration. These solids are nonputrescible, can be readily settled, and the drying does not give rise to evil odors. It would seem that the coming through of these solids, which for the most part are not further reducible and largely mineral, insures the permanence of the coarse beds.

It has been found practicable for long periods to work coarse, continuous beds 10 feet deep at the rate of 200 gallons per square yard, or 1 million gallons per acre per day, for septic effluent. At this rate results giving over 90 per cent purification are obtained after settlement of solids coming out in the filtrate; and although at this rate some of the solids are retained in the filter and there accumulate, they can be washed out by the increased flow which naturally arises with storm dilution. This possibility of dealing with storm waters is an important feature of the system.

It would seem practicable to deal with crude sewage (previously strained through several screens); but in this case a depth of 12 feet of material would be required for Leeds sewage, which is not very strong. These latter experiments have not been carried on long enough to draw from them any definite conclusions. [Dibdin, 1903.]

It was finally recommended by the Leeds experts that coarse, trickling filters be installed, either preceded by septic or chemical treatment or followed by subsequent sedimentation. Construction has been delayed on account of legal and political obstacles.

Birmingham, the fourth largest city in England, with a population of 800,000, has faced similar difficulties. The discharge of sewage into the river Tame was begun in 1852. In 1859 experiments were carried out which led, in 1872, to the installation of chemical precipitation tanks and a sewage farm. Recently a most elaborate series of large-scale experiments, unfortunately never reported in print, have been carried out by Watson, the city engineer, and have indicated the application of biological processes. In 1900 a beginning was made by converting the precipitation basins into septic tanks. The sewage is now first settled for about four hours in tanks which are cleaned once a week. Thence it passes through the open septic tanks, which have a capacity of eight hours' dry-weather flow. No sludge had been removed from these tanks after three and one-half years of operation. The septic effluent is then treated on the largest farm in England, 2,830 acres in extent, of which 1,784 acres are in actual use. The results of these various processes in 1902 are shown in Table LIII.

TABLE LIII.—*Results of sewage purification at Birmingham, England (Watson, 1903).*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	
	Dissolved.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Dissolved.	Suspended.
Average sewage	1,280	686	39.3	14.2	7	127	60.3
Sedimentation-tank effluent	1,312	346	37.7	10.9	7.3	149	92.5
Septic-tank effluent	1,180	274	48.1	8.3	3.1	121	71.8
Average land effluent	1,010	.....	1.7	.1	5.7	19	.....

It is planned in the future to settle the septic effluent in Dortmund nks and to purify it by passage through trickling beds, of which ur were in operation in 1904 (Baker, 1904).

Experiments second in importance only to those mentioned have en carried out at other large cities in England. At Leicester in 98–99 a series of investigations was made by E. G. Mawbey involv- g 16 combinations of detritus tanks, settling tanks, single, double, d triple contact beds, and land treatment. Most of these experi- ents were unfortunately of very short duration. At present the aumont-Leys sewage farm of 1,700 acres is still in operation, but the stallation of settling tanks and single-contact beds is planned for the ar future (Leicester, 1900). Huddersfield has a serious problem in e presence of large amounts of industrial waste from the scouring d dyeing of wool; but it was shown in a series of experiments car- d out between 1898 and 1900 by J. L. Campbell that chemical atment, sedimentation, and contact treatment would solve the ficulty satisfactorily (R. S. C., 1902 b). At certain hours of the day ingle treatment would be sufficient, while at other times secondary ds should be used. Triple-contact beds treating crude sewage ve good purification, but clogged badly. At Oldham studies car- d out by J. B. Wilkinson from 1898 to 1900 led to the adoption of limentation and single-contact beds (R. S. C., 1902 b). At York emical treatment has proved unsatisfactory, and since 1899 investi- tions have been carried on by A. Creer, which, as shown in Table I, indicated that septic tanks and trickling filters would best solve problem. Large-scale experimental filters have been put in opera- n, but the final construction is not yet under way (Baker, 1904).

The review of existing conditions in 1904 published by M. N. ker (1904) describes some of the most interesting plants in actual eration. At Manchester, Sutton, Exeter, Yeovil, Barrhead, Old- m, and Burnley he found septic tanks and contact filters. At Bir- ngham, Salford, Accrington, and York trickling filters were in eration. There is a strong general tendency to the conversion of l chemical-precipitation systems into septic tanks, except at Glas- w, where the former process is to be maintained. Sewage farming not extending, although it has its strong advocates and many of the rms now in use operate satisfactorily. The popularity of double- ntact beds, at a maximum five years ago, seems already on the ne. Trickling filters, either preceded or followed by septic treat- ent or sedimentation, are growing in favor (Baker, 1904).

The general progress of sewage disposal in England has been seri- sly checked by the local government board, which enjoys extraor- nary authority over any exercise of the borrowing power on the rts of municipal corporations. The sewage of towns commission

had reported in 1865 that "the right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided." The rivers pollution commission in its five reports from 1870 to 1874 recommended intermittent filtration as the best method for sewage treatment, with broad irrigation next and chemical precipitation last. The metropolitan sewage commission of 1882 reported in 1884 that chemical precipitation should be adopted by London and that the effluent should finally be treated on land. The local government board, on the strength of these precedents, has maintained a position of extreme conservatism, requiring, save in exceptional cases, that "any scheme of sewage disposal for which money is to be borrowed with their sanction should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream." The following detailed rules of the board were set forth in a circular issued in 1900: "In any sewage works three times the dry-weather flow must be treated, and an equivalent amount in addition must be provided for by special storm-water filters. Septic tanks or sedimentation basins must have a capacity equal to the dry-weather flow if followed by double-contact beds, and 50 per cent larger if followed by single-contact or trickling filters. Contact beds must not be over 4 feet deep and may receive two fillings a day, or three if automatic devices are provided. Their capacity shall be figured on an open space of 33 per cent with preliminary septic treatment or sedimentation and of 25 per cent with crude sewage. Trickling filters must be at least 6 feet deep and may operate at a rate of 1 million gallons per acre per day with crude sewage, which may be doubled with sedimented sewage or septic effluent. The effluent from either the contact or the trickling process must be subsequently treated on land, 1 acre being allowed for every 1,000 persons contributing sewage. With crude sewage on land 150 persons per acre is the limit."

In view of the experiments at London and Sutton and at Leeds and Manchester, such rules were an almost intolerable burden, and with these facts in view a new royal commission was appointed in 1898, with the Earl of Iddesleigh as chairman, to determine "what method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted." This commission made a first interim report of three volumes in 1901, a second on special chemical and bacteriological problems in 1903, and a third in two volumes on the treatment of trade effluents in 1903. Of a fourth report four volumes were issued in 1903 and 1904, three on the pollution of tidal waters, with special reference to contamination of shellfish, and a fourth (in five parts) on the land treatment of sewage. The first interim report of

)01 accomplished the chief work of the commission, since it conined the conclusion that—

It is practicable to produce by artificial processes alone, either from sewage or from tain mixtures of sewage and trade refuse—such, for example, as are met with at Leeds d Manchester—effluents which will not putrefy, which would be classed as good accord- ; to ordinary chemical standards, and which might be discharged into a stream without r of creating a nuisance. We think, therefore, that there are cases in which the local vernment board would be justified in modifying, under proper safeguards, the present le as regards the application of sewage to land. [R. S. C., 1901.]

The conclusions of the royal sewage commission throw open the ay for progress, and the developments of the next decade may be atched with interest.

On the continent of Europe progress in sewage disposal has been uch less rapid than in England. Germany is ahead of other counies in this respect, but even here the problem has not pressed eavily. The population is less dense and the rivers larger than in ngland. The installation of purification systems was slow, and hen they were found necessary land for irrigation was generally vailable. The knowledge of the process of sewage farming dated om a visit to England made in the early seventies by a Berlin ommission headed by Rudolf Virchow, and inspiration along more odern lines has similarly come from England. In 1897 of 43 nglish cities with over 70,000 population 23 treated their sewage r irrigation or chemical precipitation. In Germany at the same ne there were only nine cities with over 70,000 population having sposal systems, of which three were precipitation works and six wage farms (Kinnicutt, 1898).

The most important experimental work carried out in Germany s been that of the experiment station of the Hygienic Institute Hamburg. This was founded in 1894 to test various sewage-rification processes and placed under the charge of Doctor Dunbar director. Experiments on the contact process were begun in 97, and the studies at this station have done more than any others elucidate the theory of the contact bed. The general results indited that good effluents could be obtained from single-contact beds fine material, but that under such conditions clogging occurred, nich must necessitate the removal of the material for cleaning seval times a year (Dunbar and Thumm, 1902).

Meanwhile Schweder had installed in 1897 an experimental septic nk and contact bed at Grosslichterfelde to treat part of the sewge of Berlin. A commission appointed by the Prussian ministry the interior studied this plant in 1897–98 and arrived at the same nclusion which Dunbar had reached in the case of Hamburg Bruch, 1899).

In 1901 the royal testing station for water supply and sewage isposal was organized at Berlin, and its annual communications

since 1902 have furnished a succession of papers of the greatest value. Unfavorable results were first reported from contact beds at Tempelhof and Charlottenburg. In 1901 Zahn (1901) on behalf of the station carried out a series of investigations at Charlottenburg (Westend) which showed that nonputrescible effluents could be obtained with single contact. Experiments by Schury (1905) at Stuttgart led to similar results, septic treatment and single contact giving good results, little improved by secondary treatment. Trickling filters proved slightly better than contact beds.

The general trend of the German experimental work has till recently been in favor of single-contact treatment in beds of fine material, to be dug out and cleaned at intervals. Opinion is not favorable to the septic tank. Considerable interest has been recently manifested in the trickling filter, especially at Berlin. In spite of the great importance of the Hamburg work in relation to theoretical questions, the writers can not feel that the German experiments have furnished a fair test of the modern biological processes. It is true that German sewage is strong and contains large amounts of industrial wastes, yet in addition to these facts it seems even to local observers that the experimental filters have not been operated with the judgment and skill necessary to secure the greatest practical efficiency (Thumm, 1905).

Actual practice in Europe outside of England is still largely confined to chemical treatment and irrigation. In Germany in 1904, according to the official charts exhibited at the St. Louis Exposition, there were 254 cities with over 15,000 inhabitants. Twenty of these had no sewerage system. Of the remainder, 132 discharged their sewage into water, 84 treated it by various chemical processes, and 18 disposed of it on irrigation areas. Bredtschneider and Thumm were sent by the Berlin royal testing station and the city of Charlottenburg to study English conditions in 1903, and their report (Bredtschneider and Thumm, 1904), together with the results of the Hamburg and Berlin experiments, is likely to bear fruit in the near future. In France, too, active interest is manifested in the newer processes. A commission including MM. Calmette, Beckman, and Lannay visited England in 1900 to examine the works there in operation, and later experiments showed that the sewage of Lille could be satisfactorily treated in septic tanks and double-contact beds (Calmette, 1901).

In the United States sewage-disposal practice necessarily varies widely in different localities. New England, covered with a mantle of Glacial drift, finds the Lawrence method of intermittent filtration through sand eminently satisfactory. Following the construction of the beds at Framingham in 1889 and at Gardner and Marlboro in 1891, plants of this type have been rapidly added in Massachusetts till in 1903 there were 23 intermittent-filtration areas in the State

Massachusetts, 1904). In Connecticut in 1902 there were nine plants in operation, all sand filter beds (Connecticut, 1903).

West of the Appalachian Mountains soil conditions change, and available areas of sand become more and more difficult to obtain. The septic tank is frequently called in to remove solids and make possible the treatment of sewage at more rapid rates. The plants at Saratoga, N. Y. (Barbour, 1905), Lake Forest, Ill. (Alvord, 1902), and Pauwatosa, Wis. (Alvord, 1902), are good examples of this type.

In the Middle West the newer biological processes are rapidly gaining a foothold.

The first septic tanks at Urbana, Ill. (1894), and Champaign, Ill., have been mentioned. Septic tanks have since been installed at Kewanee, Ill. (1898), Fond du Lac, Wis. (1901), Madison, Wis.(1901), Mansfield, Ohio (1902), and a score of other places. The construction of contact beds began about 1900 and some dozen plants are now in operation, the most important being at Mansfield, Ohio (Pratt, 1905). In 1905 there were in Ohio 32 purification plants, of which 19 were sand filters and 7 contact beds; 13 made use of septic tanks at some stage in the process (Pratt, 1905). The only trickling filter of large size is at Madison, Wis.

Most of the plants in the Middle West are small and in many cases their maintenance is grossly neglected (Winslow, 1905). The city of Columbus is the first American municipality to approach the subject with a serious intention of finding the method of treatment best suited to local conditions. Here, under the direction of Hering and Fuller, a testing station was equipped in 1904, and a force of experts, including G. A. Johnson, W. E. Copeland, and A. E. Kimberley, carried out for a year an elaborate series of experiments. The station included a laboratory, one set of open tanks for preliminary treatment, and three sets of filters, with a gallery under a frame covering for each set. The sewage, amounting to about 350,000 gallons per day, was raised by a centrifugal pump to a screen chamber with two movable screens of three-eighths inch diagonal wire mesh. Next it passed to one of the tanks for preliminary treatment. These were seven in number, each 0 feet by 8 feet, 8 feet deep at the upper end and 9 feet deep at the lower end, built of wood lined with galvanized iron. The first two tanks were called grit chambers, the sewage flowing through in about one and one-half hours. The other five tanks were either "plain sedimentation" or septic tanks, in which the sewage remained eight hours or more, the difference being that the former were emptied and cleaned whenever septic action began. In the septic tanks periods of eight, sixteen, and twenty-four hours were compared.

The sewage after treatment by one of these three preliminary processes (grit chamber, plain sedimentation basin, or septic tank) was purified by treatment in one or more of thirty-five experimental filters.

These were cypress tanks 6 feet deep; one was 11 feet in diameter, four 12 feet 10¾ inches in diameter, and the other thirty 7½ feet in diameter. They were all open filters and arranged for the most part in two blocks of two rows each, with a covered dosing and sampling gallery between the rows, in which all the engineering details of operation were regulated with the greatest accuracy. Twenty-one were intermittent sand filters, two primary and four secondary contact beds of broken limestone, two coke strainers, and six trickling filters. With this plant the widest possible series of combinations was tried, including sand filters, trickling filters, and contact beds alone, either of these preceded by plain sedimentation or septic treatment, and sand filters preceded by contact or trickling filters. The results of the experiments have led to the recommendation of septic treatment, followed by trickling beds.

Plans of the sewage-purification work for a nominal flow of 20 million gallons per day have been presented to the State board of health. The plans propose septic tanks followed by sprinkling filters. The septic tanks will be 12 feet in depth, uncovered, and will have a capacity of about 8 million gallons. The sprinkling filters will be about 10 acres in area, of broken stone, 5 feet in depth, laid on hollow free-draining bottom, with sprinkling nozzles 15 feet, center to center, designed under a 5-foot head to spray the septic sewage over the surface of the broken stone, at a net rate of 2 million gallons per acre per day. The effluent from these filters will be collected in settling basins with a capacity of 4 million gallons. [Griggs, 1905.]

In the extreme West a third set of conditions confronts the sewage expert. The arid climate here makes the sewage of special value for irrigation and the sparseness of population renders sewage farming the most profitable means of treatment. Following the early broad-irrigation areas at Cheyenne, Wyo. (1883), Greeley, Colo. (1890), Hastings, Nebr. (1892), Los Angeles, Cal. (1892), and Trinidad, Colo. (1892), a dozen or more plants have been laid out and are in operation, the largest in 1904 being at Los Angeles, Cal., Salt Lake City, Utah, and Hastings, Nebr.

Chemical-precipitation plants, built before the newer processes were developed, are maintained at Alliance and Canton, Ohio, and at other places to avoid the cost of change. At Providence, R. I., on account of special local conditions, this process seems well adapted for continued use.

In a comprehensive review of conditions in the United States, Fuller (1905 a) states that of 1,524 cities and towns with a population over 3,000, 1,100 have sewerage systems and 90 have purification plants. Among these 90 plants are 14 irrigation areas, 41 intermittent sand filters, 13 chemical-precipitation works, 29 septic tanks, and 10 rapid filters of coarse materials. The fact that of a population of 28,000,000 connected with sewerage systems the sewage of 20,400,000 is discharged into fresh water and of 6,500,000 into the sea furnishes some indication of the problem which must be met in the near future.

EXPERIMENTS ON THE PURIFICATION OF BOSTON SEWAGE, 1903-1905.

THE SEWAGE EXPERIMENT STATION.[a]

The sewage experiment station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany street and Massachusetts avenue, at

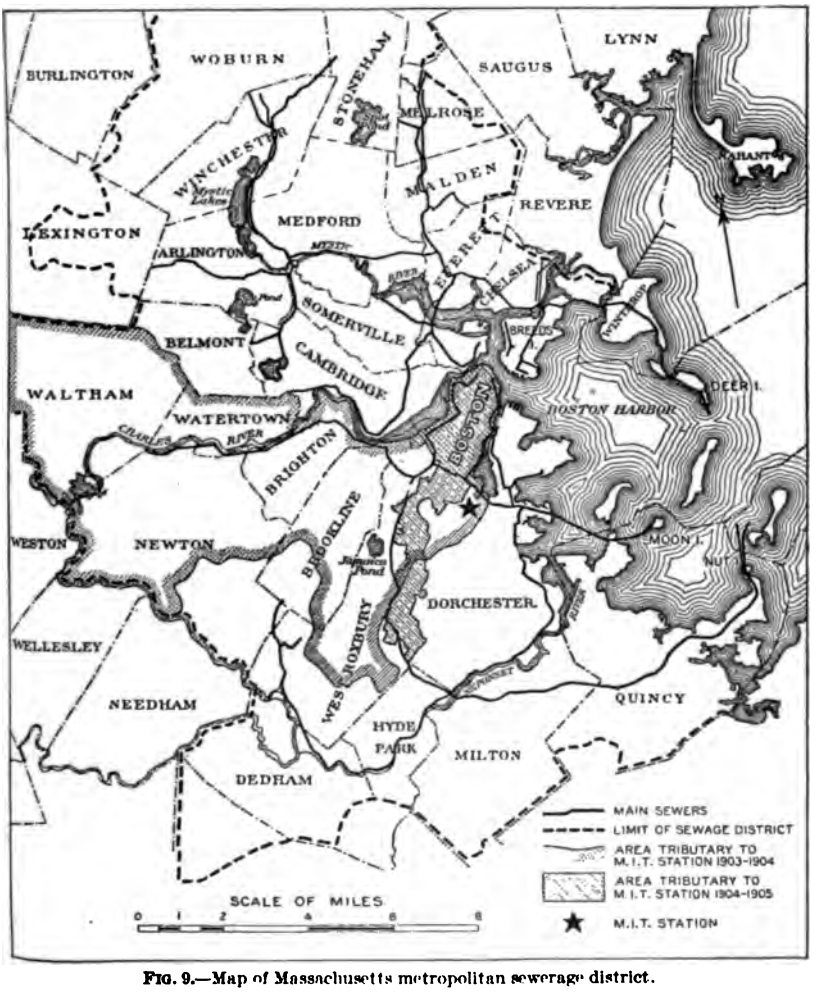


FIG. 9.—Map of Massachusetts metropolitan sewerage district.

he point indicated by the star on the map (fig. 9). Connection is ade with the 9-foot sewer of the Boston main drainage system at a oint on Massachusetts avenue about 200 feet below the entrance of

[a] The foundation of this station and the object of the experiments are described in the introduction (p. 5-9).

the Albany street intercepting sewer. Prior to October 14, 190 age from the whole of Boston south of the Charles, with the exc of the Dorchester and South Boston districts, together with collected by the south metropolitan sewerage system from Wa Newton, Watertown, Brighton, and Brookline, flowed past the intake. This contributory area is shown in fig. 9. In 190 flow above the station was more than 50 million gallons a day district with a contributing population of 350,000, sewered

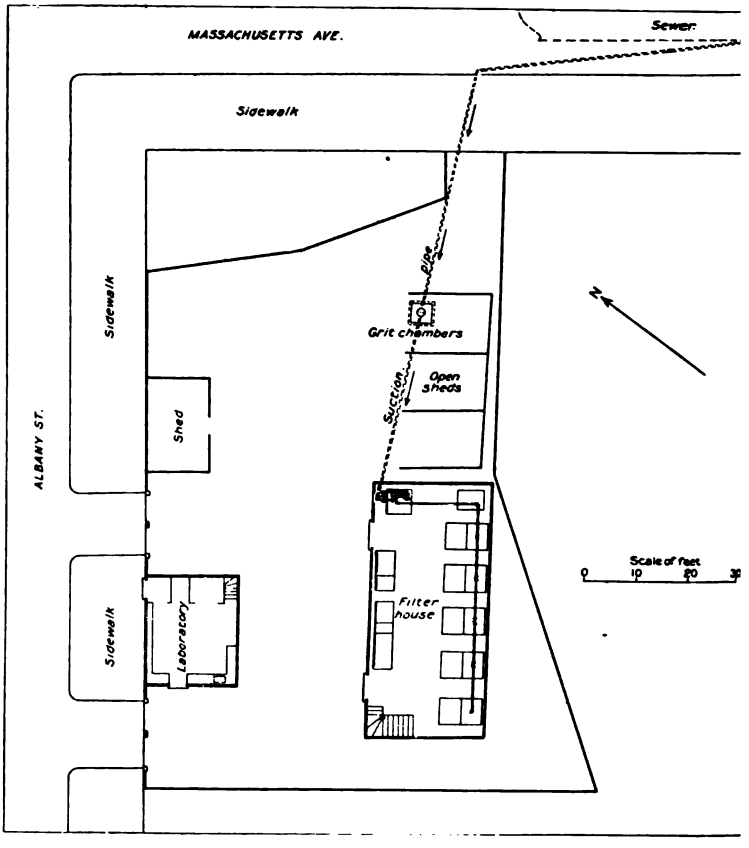


FIG. 10.—Plan of Massachusetts Institute of Technology experiment-station grounds and

most part on the combined system. Since October, 1904, th pletion of the new high-level sewer and of the Ward street p station has resulted in the diversion of all the sewage from the politan district, outside of Boston proper, to the new sewer, ishing the average daily flow past the station intake by one-fourth. The location of the station and of the intake pi reference to the sewers is best seen in the accompanying plan (fig. 10).

A 2½-inch galvanized-iron suction pipe runs directly to the station ımp from a point in one of the sewer manholes about 10 feet below e surface of the street. To the lower end of this pipe is coupled a -foot length of rubber suction hose of 3 inches internal diameter. ıis hose would reach to the bottom of the sewer in the absence of any w, but is carried by the strong current to a nearly horizontal posi- ın at its lower end, so that it is suspended at about mid-depth. ıe flow is so strong that the sewage is well mixed throughout. At ɜ end of the hose is a strainer made from a 3-foot length of 6-inch ought-iron pipe in which eight ½-inch longitudinal slots have been t from a point near one end through the other end. The open end protected by a plate fastened within and having deep notches cut lially to correspond with the slots in the pipe. Such a device is ınd to be largely self-cleaning, allowing a free movement toward e end, of any material which is drawn lightly into one of the slots. rainers of the ordinary type clog badly. Even with the slotted pe the end must be hauled up each day, or oftener, and the rags ıd other material collected on it removed. The rubber suction pe is joined to the iron pipe above it by a "quick-as-a-wink" ıupler, a clamping device sometimes used in fire apparatus for aking quick connections without screwing. With this coupler the ıtire suction pipe can be disconnected and hauled up without bend- g it—a method which it is necessary to adopt in cleaning the end times of very high water. Just before reaching the pump the suc- ɔn pipe passes through a grit chamber, where it deposits the heavier ırticles of sand and cinders. This chamber was put in at the sug- stion of Mr. Leonard Metcalf, who furnished its design and other endly suggestions. It consists of a cast-iron cross of stock water- pe pattern. The diameter of the large arm, which rests vertically ıd constitutes the chamber, is 19 inches and its depth 16 inches. The her arm is 2½ inches in diameter and connects with the suction pipe flanges. Blank flanges form the top and bottom of the chamber and e bolted on and made tight by rubber packing, so that the top of the ıamber may be readily removed for cleaning. A vertical grating of ılf-inch square iron bars, placed so as to give a clear space of half an ch between them, divides the chamber into two parts and serves to tain any rags or other large material which may have escaped the ction strainer. The chamber is placed on the line of the suction pe 8 feet below the surface of the ground and is covered by a heavy ıme structure of pyramidal form, 6 feet square on the bottom. ɔm the grit chamber the suction pipe runs direct to the cellar of the ter house. Details of the grit chamber are shown in fig. 11.

The filter house is a two-story frame structure, the interior arrange- ent of which is made clear in figs. 12, 13, and 14. Fig. 12 is the ɔund-floor plan, showing the arrangement of the filter tanks and

the pump pit. Fig. 13 is a plan of the second floor, indicating t position of the supply tanks, septic tanks, and sand filters. Fig. is a midsectional elevation bringing out the vertical arrangemen the various parts of the plant.

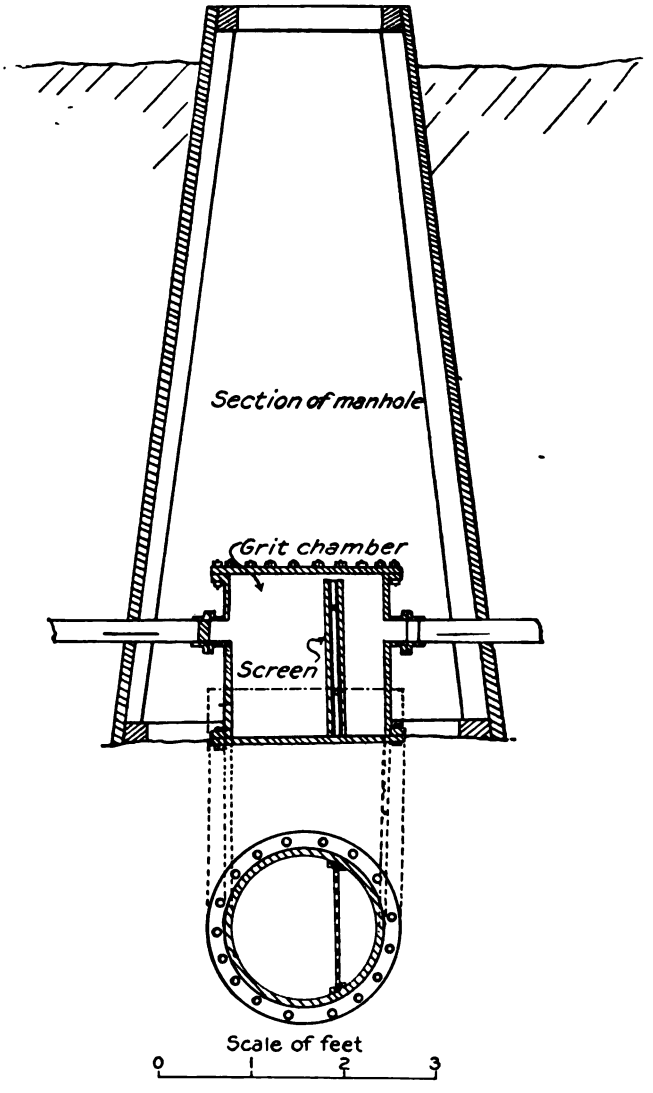
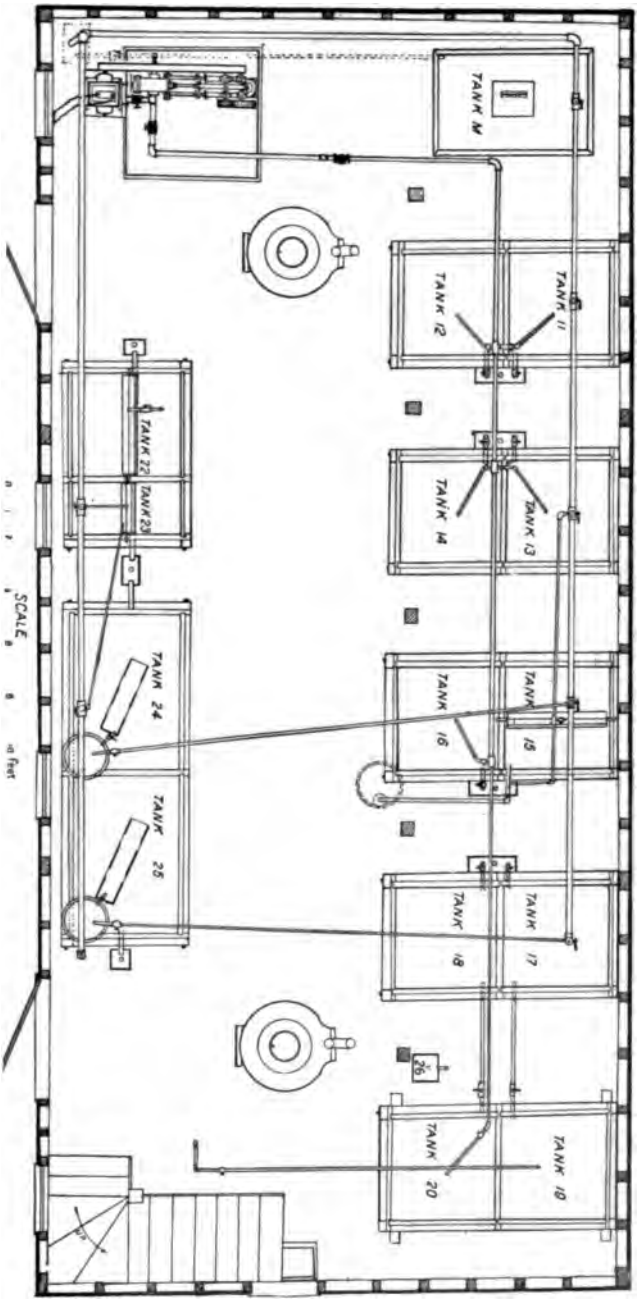


FIG. 11.—Detail of grit chamber.

The position of the pump is shown in fig. 12. It is a 4 duplex Warren power pump driven by a 2-horsepower induction r under 110 volts alternating current of 66 frequency. The plunge the cup type. It is found that this form protects the compo *lining of* the cylinder much more perfectly than a packed plu

es are of the clapper type, with rubber packing, which is r renewed. The pump is placed in a pit 7 feet below the



he filter house. The total suction lift is 16 feet, reckoned *average dry-weather* elevation of the sewage surface to

the pump valves. This lift may be increased to 20 feet at times of low flow. The pump is supplied with a vacuum gage, which

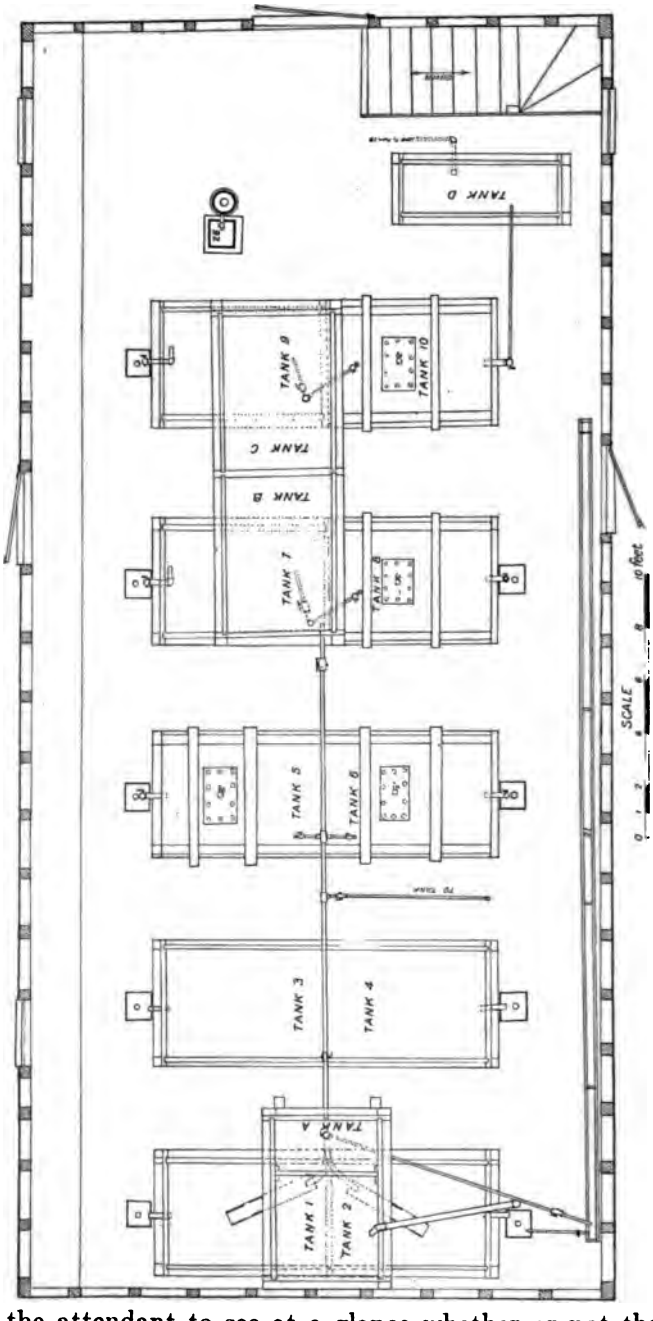


FIG. 13.—Plan of second floor of filter house.

enables the attendant to see at a glance whether or not the valve are performing their duty and whether any stoppage of the strainers has

he sewage is delivered through a 2-inch force main to supply
: A, best shown in the sectional elevation (fig. 14). The lift
ı the pump valves to the tank is 25 feet. The supply tank is
; 6 feet in area and 2 feet deep. The sewage enters the tank
· the side near one end, passes over the weir shown in the sec-
, and thence through pipes to supply tanks B and C and to the
ous filters. Tanks B and C are each the size of A and are con-
ed with each other by holes through the dividing partition.
y serve primarily to give a constant flow through the septic
:s, which are placed at a lower level on the same floor, and to
trickling filters on the floor below. The two tanks have a com-
d capacity of about 700 gallons, which is a two hours' supply
:he continuously working tanks and filters.

ilters Nos. 1 and 2 are sand filters. Tank No. 1 is a cypress tank
· 6 feet in area and 3 feet deep. It contains 2 feet of common
:ial drift sand with an effective size of 0.17 mm. and a uniform-
:oefficient of 3.5. This layer of sand rests on 6 inches of under-
n material graded from 4-inch cobbles at the bottom to buck-
at gravel just beneath the sand. The outlet of the filter is a
:h iron pipe open at all times and not trapped. Filter No. 2 is
filter No. 1 in all respects, except that it contains a layer of
l but 1 foot thick over the underdrain material. The two tanks
built together, as shown in fig. 13.

ıe six septic tanks, numbered 5 to 10, are also built in pairs
are of the same dimensions as the sand-filter tanks, namely,
· 6 feet and 3 feet deep. Tanks Nos. 7 and 9 are uncovered.
other four are covered as tightly as possible with wooden cov-
These covers are not absolutely gas tight. Tank No. 6 is
l with crushed stone about 1½ inches in diameter. All the
:s and filters on this floor, except No. 10, drain into small catch
ıs connected with the main drainpipe underneath the floor.
arrangement is shown in fig. 14. Each drainpipe may be
:d off from the main drain by a cock just above the latter and
tank effluent diverted to the filters below. Tank No. 10 drains
:tly into the small tank D, which is 2 by 6 feet and 2 feet deep.
is used to flood a contact filter below.

.lter tanks Nos. 11 to 16 are all cypress tanks 4 feet square and
:t deep, built together in pairs. Tanks Nos. 17 to 20 are of the
e area, but only 4 feet deep. The pair Nos. 19 and 20 are at a
.er elevation, so that their effluents can flow to the other pair,
. 17 and 18, respectively.

ank No. 15 is a trickling filter, receiving the septic sewage from
: No. 5. Tanks Nos. 11 to 14 and Nos. 16 to 20 are contact filters.
k No. 11 is filled with coke 2 to 3 inches in size; tanks Nos. 12,
19, and 20 with crushed stone 1 inch to 1½ inches in size, and

tanks Nos. 13, 16, 17, and 18 with one-fourth to one-half inch crushed stone. Tanks Nos. 17 and 19 constitute one double-contact

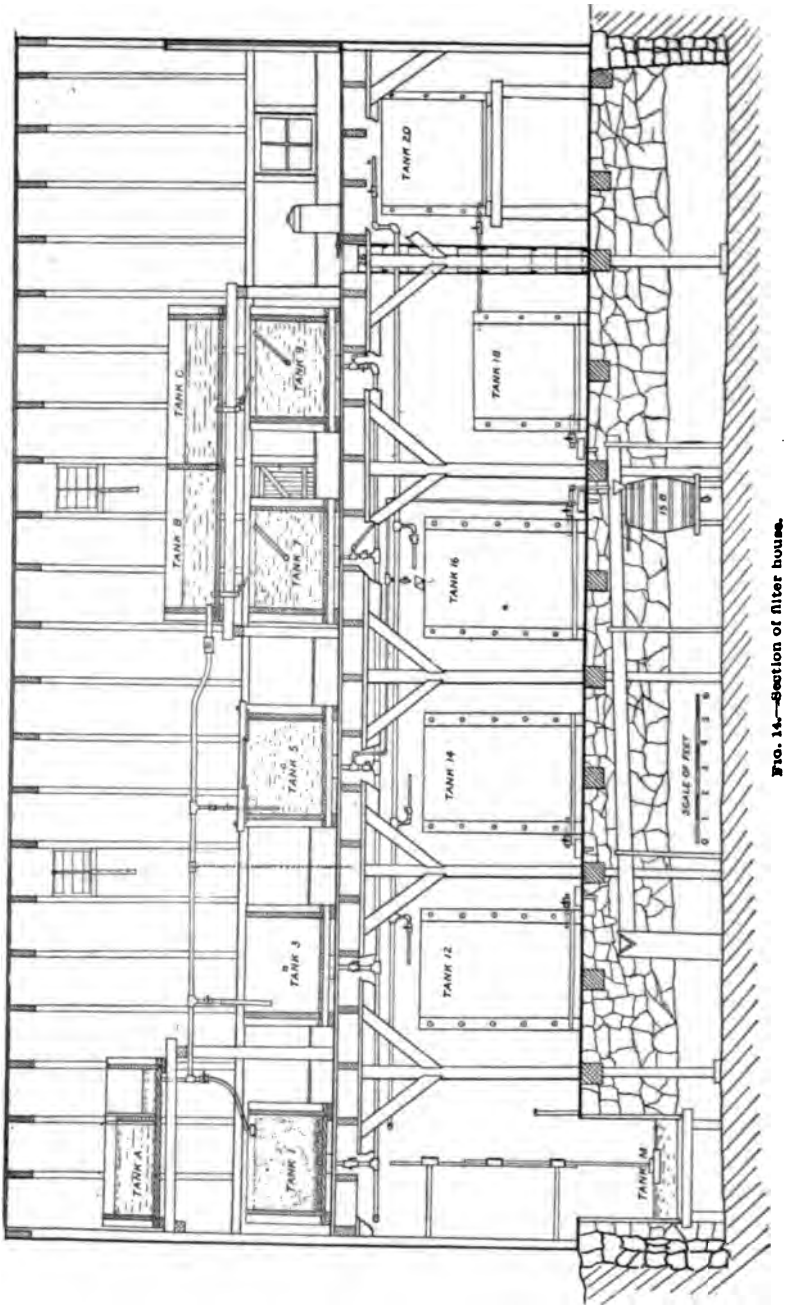


FIG. 14.—Section of filter house.

system and Nos. 18 and 20 another. Tank No. 14 is the only o *which has* been altered during the experiments. During the fi

ar it was filled with crushed stone between one-half and 1 inch in ameter. In June, 1904, it was emptied and filled with Raritan cing brick, 1½ by 4 by 12 inches, so laid in even tiers as to give e maximum of open space. Tank No. 22 is 4 by 4 by 6 feet, and No. is 4 by 2 by 6 feet, the two tanks forming a pair. They are ed with 1 inch to 1½ inches crushed stone and are operated as ckling filters. Sand filters Nos. 24 and 25 are exact counterparts filter No. 1. The filters on the lower floor all drain into catch sins similar to those on the upper floor already described. These ipty directly into a main drain underneath the floor. In the case filters Nos. 15 and 22 the effluent runs into a barrel provided th an overflow. These barrels provide a two hours' storage for e effluents, so that the effect of that period of sedimentation may studied. The barrel under filter No. 15 is shown in fig. 14. ink M is used as a measuring tank. It is fitted with a float gage, refully calibrated, reading by means of a vernier to the nearest llon. The principal statistics of the tanks and filters are brought gether in Table LIV for convenience of reference.

TABLE LIV.—*Statistics of experimental tanks and filters.*

Dimensions (feet).	Description.	Material.	Size.
4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
4 by 6 by 3	do	do	Do.
4 by 6 by 3	Sampling tank		
4 by 6 by 3	do		
4 by 6 by 3	Septic tank		
4 by 6 by 3	do	Stone	1 inch to 1½ inches.
4 by 6 by 3	do		
4 by 6 by 3	do		
4 by 6 by 3	do		
4 by 6 by 3	do		
4 by 4 by 6	Contact filter	Coke	2 to 3 inches.
4 by 4 by 6	do	Stone	1 inch to 1½ inches.
4 by 4 by 6	do	do	¼ to ½ inch.
4 by 4 by 6	do	Stone Brick	½ to 1 inch.
4 by 4 by 6	Trickling filter	Stone	1 inch to 1½ inches.
4 by 4 by 6	Contact filter	do	¼ to ½ inch.
4 by 4 by 4	do	do	Do.
4 by 4 by 4	do	do	Do.
4 by 4 by 4	do	do	1 inch to 1½ inches.
4 by 4 by 4	do	do	Do.
4 by 4 by 6	Trickling filter	do	Do.
4 by 2 by 6	do	do	Do.
4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
4 by 6 by 3	do	do	Do.

According to the plan of the experiments each unit differed from ch of several other units by only one variable condition. In this ay the results of the whole series may be studied together as one periment, and it is possible to note the results of changing any one riable condition, the others being constant. Among the variables hich have been studied in this way are, first, of course, the various pes of purification processes and the coincident necessary variation the rate of filtration. Then under each principal type of process wo or *more of the following* conditions have been compared, the

variables, as stated, being introduced one at a time: Different kinds and sizes of material, different depths of bed, single versus double contact, fresh versus septic sewage of different ages, and open versus closed septic tanks. With the sand filters four combinations have been studied, each differing from each of the others by only one of these variables; with contact filters, six combinations; with trickling filters, three; and with septic tanks, three, which, together with one primary comparison of the main types, makes a total of seventeen combinations of the variables mentioned.

On the sand filters Nos. 1 and 2 the volume of sewage applied has been measured by a float in the supply tank over the filter. The pump was stopped while these filters were receiving their doses. Sand filters Nos. 24 and 25 were dosed from the barrels shown in fig. 12. These barrels contain the exact amount of one dose. Sewage was distributed over the surface of the sand filters by means of small wooden troughs with side openings at intervals. Application of sewage to the contact filters was made by means of a single half-inch pipe discharging horizontally over the filter. The filling was in all cases continuous, about half an hour being allowed for the process. The amount of sewage applied to the contact filter is of course its own liquid capacity multiplied by the number of doses applied daily. To obtain this value and also to study the progressive loss of capacity of contact filters under various conditions very careful measurements of the capacity of all the filters have been made at weekly intervals. For this purpose the measuring tank M was used. Connection with the filter outlet was made by means of a rubber hose, and the total effluent of the filter was run into the measuring tank after the height of sewage within the filter had been noted.

The trickling filters were dosed by means of tipping buckets, long V-shaped troughs divided by a longitudinal partition into two equal parts. As one side fills the weight of sewage overbalances the system and the bucket tips, emptying the full side and bringing up the other side so that it receives the flow and tips in its turn. In this way the sewage is splashed in successive doses over the two halves of the filter alternately.

By connecting an ordinary cyclometer to this tipping bucket it has been possible to record the number of tips and indirectly the total flow. The apparatus was originally rated, and occasionally checked by allowing the effluent to flow into the measuring tank for a period and comparing the readings of the cyclometer with those of the float gage.

The closed septic tanks were regulated at their outlets, free communication being allowed with the supply tanks overhead. The open tanks were maintained at a constant level by overflow pipes and were regulated at the inflow pipe. All these tanks were under

the constant observation of an attendant both day and night, and the rates of flow were determined at frequent intervals by filling a 10-quart pail.

In sampling, a representative sample of the crude sewage was obtained by allowing a portion of the regular pumpage to flow slowly into a tank of 540 gallons capacity, filling the tank in about three hours during each morning. The sewage in the tank was then thoroughly mixed and sampled. Trickling effluents and sand-filter effluents were collected whenever running. Contact-filter effluents were collected at about the middle of the discharge. Analyses of each effluent were made weekly and of the sewage five times a week.

ANALYTICAL METHODS AND INTERPRETATION OF RESULTS.

In the comparison of two sewages from different localities the term "strength" is often used in such a loose way that its significance is more or less obscure. Strictly the strength of a sewage is measured by the amount of certain elementary constituents which it contains, as, for example, the amount of nitrogen present. Only on such a basis can any fair comparison of sewages be made. The use in this connection of constituents so partial and changeable as the free or albuminoid ammonia or the oxygen consumed is misleading. These constituents are in a state of constant change in any given sewage, and hence can not satisfactorily determine its real strength. This point is well illustrated by the analyses in Table LV, taken from the reports of the Massachusetts State board of health for 1903 (Clark, 1904). The first line represents a nine months' average of weekly analyses of the Lawrence street sewage taken directly from the sewer—a fresh sewage. The second line represents analyses of the same sewage for the same period after it had been pumped through about half a mile of pipe and subjected to sedimentation and septic action.

TABLE LV.—*Comparison of fresh sewage at Lawrence with the same sewage after passing through long pipe, April to December, 1903 (Massachusetts, 1904).*

[Parts per million.]

	Nitrogen as—		
	Free ammonia.	Albuminoid ammonia.	Total organic.
Lawrence street sewage	18.1	5.8	23.4
Station sewage	39	5.2	13.3

The increase in the free ammonia and the decrease in the total organic nitrogen are characteristic of what occurs in stored sewage. Such partial values as are given by determinations of albuminoid ammonia and oxygen consumed do not, therefore, stand in any constant relation to the total figures—for organic nitrogen and carbon

respectively—and hence in different sewages give different proportions of the whole.

Total nitrogen and total carbon values are, then, to be desired in the study of sewage purification. The latter are out of the question, since there is no available method for this determination sufficiently simple for routine use. Total nitrogen values have also been generally ignored until very recently, and these experiments were nearly half completed before their paramount importance became evident. Throughout the present series of studies, therefore, the old determinations of free and albuminoid ammonia and oxygen consumed have been maintained. These must be taken for what they may be worth as roughly representative of the total organic matter.

In this connection it is useful to remember that both the free and the albuminoid ammonia in sewage increase with age, and that the ratio of albuminoid ammonia to organic nitrogen increases at a corresponding rate. In a fresh sewage the albuminoid ammonia is roughly one-third the free and the organic nitrogen generally over three times the albuminoid. As the albuminoid-free ratio decreases the organic-albuminoid ratio decreases at almost the same rate, and Fuller (1903) has found that the former ratio is roughly about one-twelfth the latter; put into algebraic form this becomes—

$$\frac{12 \times \text{albuminoid nitrogen}}{\text{ammoniacal nitrogen}} = \frac{\text{organic nitrogen}}{\text{albuminoid nitrogen}}$$

whence

$$\text{organic nitrogen} = 12 \times \frac{(\text{albuminoid nitrogen})^2}{\text{ammoniacal nitrogen}}$$

This formula is only roughly approximate, but is perhaps the best conversion formula yet devised.

The commonest method of measuring the work of a filter is by the percentage of purification obtained when the amount of some one of its constituents is compared in the crude sewage and the effluent. Dunbar and Thumm (1902) have attempted to justify this practice on theoretical grounds, claiming that percentage of purification, figured on oxygen consumed, runs parallel with keeping properties, irrespective of the original strength of the sewage. It may be assumed that some such general relation exists and that for a given process of purification on a given sewage it might be found with some degree of accuracy, but that the result is of general application to filters of all types and sewages of all kinds seems, in the absence of further evidence, improbable. Even though it may be true that a certain type of filter would produce a stable effluent by oxidizing one-half its organic matter, it does not necessarily follow that another type, working through characteristic and entirely different reactions, would produce the same result by the same percentage of oxidation. The

amount of available oxygen in an effluent is also of importance in relation to its stability, and of two effluents showing exactly the same percentage of purification, one might be quite stable by virtue of its high nitrate and oxygen content and the other putrefactive owing to the absence of these substances. Such a difference is observed between effluents from a contact and a trickling filter. A contact filter running in a typical manner has already carried out during its cycle those secondary reactions by which oxygen and nitrates are used up for the oxidation of organic matter. Such an effluent is practically free from reserve oxygen and must for stability be purified to a much greater degree than would be the case with that from a trickling filter in which, by virtue of a reserve of oxygen, the oxidation may proceed after discharge.

The character of an effluent, with respect to its stable or putrescible character, is the thing of paramount importance. The effluent from a good sand filter will show so little organic matter and so high a nitrate value that there can scarcely be a moment's question about its quality after an inspection of the general analytical results. With the newer rapid processes of sewage treatment, however, effluents of such high purity are rarely obtained. In practice it is generally the aim to produce, not the best effluent possible, but merely one which can be discharged, under existing conditions, without creating a nuisance. Such a requirement may be fulfilled by an effluent containing considerable amounts of organic matter if two conditions be present: (1) A sufficient amount of reserve oxygen in the effluent to unite with all readily oxidizable organic matter and thus prevent the development of anaerobic conditions; and (2) a stability of the organic matter by virtue of which it does not readily undergo putreactive decomposition. A measure of this quality of stability is the essential in judging of an effluent.

Endeavors have been made to develop a relation between the ordinary analytical data and the keeping qualities of an effluent. It must be confessed, however, that the determination of the oxygen consumed and of the various forms of nitrogen, while serving to identify undoubtedly good or bad effluents, fails to discriminate between a partially purified effluent which is perfectly stable and a similar one which is not. It is therefore necessary to fall back on a practical test of keeping quality as furnished by the incubator test. In this test, devised by Scudder (R. S. C., 1902 a) and since modified by others, the sample is bottled up and kept in the incubator at a warm summer temperature from three to five days. If at the end of that time it is still sweet and does not consume much more oxygen from permanganate than it did initially, it is pronounced a stable effluent.

In the tests at this station a modification of Scudder's method has been used. The sample, as in Scudder's work, was stored for five days at 37° and the oxygen consumed from permanganate was determined in the cold. In the Boston sewage and effluents, however, there are considerable amounts of readily oxidizable nonorganic materials, chiefly hydrogen sulphide. In order to exclude these substances the oxygen-consumed value was determined twice, once immediately on the addition of the permanganate and again after three minutes. The difference between the two results represents the true oxygen-consumed value. This method was suggested by Messrs. Johnson and Kimberly, of the Columbus experiment station.

The determination of total and suspended solids, which should form an integral part of every sewage analysis, was made for a considerable period. Unfortunately the enormously high chlorides in the Boston sewage, due to sea water, entirely masked the suspended solids when the determination was made in the ordinary way, and the direct determination of suspended solids by the Gooch crucible method was begun too late to get a large series of results. In the present paper, therefore, it is possible to report only, as an indirect measure of suspended solids, turbidity readings made with the Jackson turbidimeter (Jackson and Whipple, 1901), recalibrated for coarse material as described by Phelps (1905 a).

The determinations actually carried out on each sample in these experiments were as follows: Free and albuminoid ammonia, nitrates and nitrites, oxygen consumed and oxygen dissolved, turbidity, and odor. The albuminoid-ammonia and oxygen-consumed determinations were made on both the filtered and unfiltered samples. In addition to these regular determinations, an average sample was collected during the week, by adding each day to a bottle a definite amount of sewage sterilized with chloroform. On this average sample weekly determinations were made of chlorides, sulphates, iron, and alkalinity.

Analyses were made according to the methods generally employed in this part of the country, as described by Richards and Woodman (1904). Permanent standards have been used for the ammonia readings, as suggested by Jackson (1900). For the nitrite standards the Jackson permanent standards were used during a portion of the time, but it was soon found that a dilute solution of fuchsine, made up to match the desired nitrite reading by eye, gave a perfect standard as far as shade was concerned and was sufficiently permanent for all purposes. This is essentially the method since described by Weston (1905). Nitrates were determined by the Brucine method of Noll (1901), as described by Farnsteiner and his associates (1902

For the oxygen-consumed determination the Kübel method was used, boiling for two minutes. In future work it is the intention to follow throughout the procedure outlined by the committee on standard methods of the American Public Health Association.

In tabulating the results of these experiments all ammonia, nitrite, and nitrate values are reported in terms of nitrogen, and all chemical results are expressed in parts per million. The dissolved oxygen is reported in this way rather than in the conventional form of per cent of saturation, since, while the latter method of expression may have had some significance in the study of surface waters, it has no value whatever in connection with sewage or filtration work in general. Owing to a change in the temperature of the water during treatment the results expressed in per cent of saturation may show an increase in the amount of oxygen, while in reality there is a marked decrease.

CHARACTER OF THE CRUDE SEWAGE.

During the two years of the operation of the sanitary research laboratory almost daily analyses of the crude sewage have been made. The sewage analyzed, as already explained, is a sample of the flow from 9 to 12 a. m. which has passed through the screen and grit chamber, drawn directly from the supply tank without any further chance for sedimentation or straining. The amount and character of the material previously removed from the grit chamber and supply tank are discussed on pages 115–116. Table LVI (p. 114) gives quarterly averages of the samples, taken, as a rule, on five days of each week. Yearly averages are also shown, the year being taken for convenience from June to June. Detailed studies of hourly and seasonal variations in the composition of the sewage have been previously reported (Winslow and Phelps, 1905).

The organic constituents of Boston sewage appear to be fairly normal in relation to one another. As stated above, regular determinations of the organic nitrogen were not made, but from the results of about fifty such determinations made at various times in the course of experimental work it may be stated that the average organic-nitrogen figure for the whole period would be about 20 parts per million. In this respect the sewage appears to be of about the same strength as the average sewage of Massachusetts cities, being slightly weaker than the sewages of Lawrence and Gardner (new system) and somewhat stronger than those of Framingham, Worcester, and Brockton.

The inorganic analyses of mixed weekly samples covering the calendar year 1904 showed an average of 2,300 parts per million of chlorine, 15 parts of iron, 125 parts of alkalinity, as calcium carbonate, and 220 parts of SO_3 as sulphates. The high chlorine and sulphate values are

due to the large amount of sea water present in the sewage of Boston. If the chlorine normal to the sewage itself is assumed to be equal to the total nitrogen, as is commonly the case, a simple calculation shows

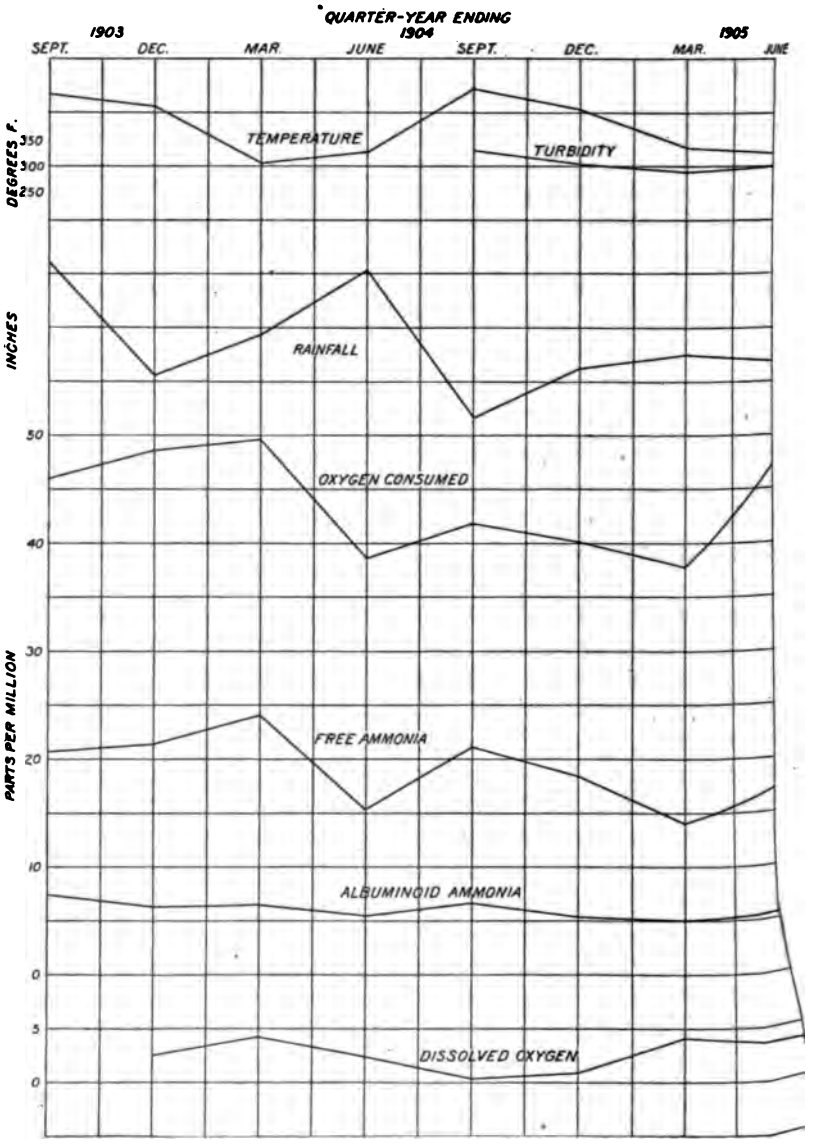


FIG. 15.—Composition of the crude sewage of Boston.

that the amount of chlorine present represents a volume of sea w equal to 11 per cent of the total volume of the sewage. This, h ever, is only an average value for the period. During each tw hours the chlorine reaches a maximum figure of from 3,000 to 4,

s per million, representing 19 per cent of sea water, while between e maxima there are minimum points of about 200 parts per mil- representing only 1 per cent of sea water. It may be an impor- question in any project for the purification of Boston's sewage ther the extra cost of pumping and of treating this sea water ıt not be greater than the cost of keeping it out of the sewers. the other hand, there is the possibility that this large amount of water, saturated as it is with oxygen, may be of actual advantage ıy aerobic process of treatment.

'ith regard to the variations in strength at different periods, the point of importance to be noticed is the slight falling off in the ıgth of the sewage during the second year as compared with the . This effect may probably be attributed to the fact previously tioned (p. 98) that on October 14, 1904, the sewage of the upper of the drainage system was diverted to the new high-level sewer. h of this upper drainage area is sewered on the separate system, ground water is in the main excluded. Furthermore, even with combined system, the relative amounts of rain water entering the ɜr is much greater in the city of Boston, with its great area of ed streets, than in smaller places with more open spaces and ller relative amounts of pavement. It might also be possible, ı the increasing per capita water consumption noticed in all cities ı year to year and amounting in the metropolitan water district to 3 per cent per annum, that there would be a resulting decrease in strength of the sewage. On the other hand, the low rainfall dur- 1905 must have operated in an opposite direction.

he quarterly variations in the strength of the sewage are consid- ›le, and, as is shown on pages 122–123, markedly influence the efflu- ı of the various purifying processes. The controlling cause in ıe seasonal variations is the rainfall. The first effect of a shower › increase the oxygen consumed by the introduction of street wash- ı. A long period of rain, however, has the opposite result. The eral rule, as has been stated elsewhere (Winslow and Phelps, 5), is that sewage is weakest in spring and summer. The precipi- on was unusually low in the summer of 1904 and the spring of)5, and therefore the seasonal relations for the second year are ıewhat abnormal.

TABLE LVI.—*Composition of Boston sewage (quarterly averages), 1903–1905.*

Date.	Number of samples.	Temperature (° F.).	Analyses (parts per million).									
			Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
				Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
				Total.	In solution.	In suspension.				Total.	Soluble.	
June to August, 1903	27	67	.....	7.4	3.4	4	20.7	0.	0.1	46	.....	.....
September to November, 1903	42	62	.....	6.2	3.1	3.1	21.3	.41	0	48.7	.....	2.4
December, 1903, to February, 1904.	10	51	.....	6.6	3.6	3	24	.42	0	49.6	.....	4.2
March to May, 1904	32	55	.....	5.4	2.7	2.7	15.3	.14	0	38.7	22.5	2.3
June to August, 1904	47	69	330	6.7	3	3.7	21	.16	.2	41.9	23.7	.3
September to November, 1904	33	61	300	5.4	2.6	2.8	18.4	.22	.4	40.2	22.2	.9
December, 1904, to February, 1905.	44	47	300	5	3.1	1.9	14	.10	.2	38.6	25.7	4.2
March to May, 1905	35	45	300	5.6	3.1	2.5	17.2	.08	0	47.4	27.3	3.6
June, 1903, to June, 1904 [a]	102	60	.....	6.3	3.1	3.2	19.7	.27	.1	45.2	22.5	2.8
June, 1904, to June, 1905 [a]	153	58	305	5.7	3	2.7	17.6	.14	.1	41.5	24.6	2.2
June, 1903, to June, 1905 [a]	255	59	305	5.9	3	2.9	18.5	.19	.1	43.1	23.8	2

[a] Yearly and biyearly averages given in this and subsequent tables are obtained by averaging the daily results and are therefore not averages of the quarterly figures given.

REMOVAL OF SUSPENDED MATTER.

In any discussion of the solids in sewage it is necessary to distinguish clearly between three classes of suspended matter. In the first place, there are generally present large floating objects, such as rags, paper, sticks, and other gross débris. Before pumping sewage it is customary to pass it through screens for the separation of such material, which may therefore be denoted as screenings. Another class of matter, present especially in sewage which includes street washings, consists of sand and other heavy mineral particles, sharply distinguished from the ordinary sewage sludge by the rapidity with which they settle out when the sewage is brought either to complete rest or to a low velocity of flow. Chambers or tanks for the removal of such material are commonly called grit chambers or detritus tanks, and the material may be conveniently spoken of as detritus. After the removal of the screenings and the detritus there remains in suspension the sewage sludge proper, composed of finely divided matter largely organic in nature which settles out only at a low velocity, and then but slowly.

As a rule it is found desirable to screen sewage which is to be pumped and to settle sewage which has to pass through an inverted siphon, as is the case with that of the south metropolitan district. Where any purification is to be carried out both these preliminary treatments are generally advisable. The amount of solid material removed is often considerable. At Manchester, England, during 1904, the amount of combined screenings and detritus amounted to about 4,000 tons from a total of 13 billion gallons of sewage, or about 7,000 pounds per million gallons (Manchester, 1904). At Boston during

903 about 10,000 cubic yards of detritus were removed from the settling chamber at the Dorchester pumping station from a total volume of sewage of 32 billion gallons, an average of about 0.31 cubic yard per million gallons. The composition of this detritus is not known, but a fair estimate would be 60 per cent of water and a solid content of 1½ tons per yard, making 900 pounds per million gallons of sewage (Boston, 1904). The amount of screenings removed during 1897 was recorded and found to be about 1,000 cubic yards, or, roughly, 500 tons, an average of 300 pounds per million gallons of sewage (Boston, 1898).

In the experiments at this station, as noted above, screenings and detritus were taken out by a grit chamber and to a slight extent by supply tank A. During the actual time of pumping the pump discharges on an average about 1,000 gallons per hour, which produces a velocity of 1.1 feet per second in the 2½-inch suction pipe. The velocity is checked in the grit chamber, being reduced to an average of 0.04 foot per second, and the time occupied in passing the grit chamber is about forty-five seconds. Since March, 1904, when the grit chamber was installed, a careful record of the amount of sediment removed has been kept, the whole amount carefully sampled, and an aliquot portion preserved for analysis. A small amount of material removed from supply tank A has also been weighed and sampled and mixed with the grit chamber material in proportionate parts.

The amount of detritus removed by the grit chamber amounted in sixteen months to 4,800 pounds, or 2.4 cubic yards, of wet material from a total volume of sewage equal to a little over 3 million gallons—1,600 pounds, or 0.65 cubic yard per million gallons. All the material thus removed was carefully sampled and its moisture determined. A portion of each dried sample was preserved and mixed with proportionate parts of later samples, and the mixture was finally analyzed. A certain portion of each sample, consisting largely of clean stone, was not included in the analysis. The amount of moisture, the proportions of clean stone and of dry detritus, and the analysis of the latter are shown in Table LVII, first in total amounts and then in parts per million of the total volume of sewage (3 million gallons).

TABLE LVII.—*Amount and composition of detritus removed from grit chamber from March 26, 1904, to June 1, 1905.*

	Wet detritus.	Water.	Clean stone, etc.	Total.	Fine, dry detritus. Loss on ignition.	Organic nitrogen.	Organic carbon by permanganate.
Total pounds	4,800	1,300	570	2,900	319	6.6	5.1
Pounds per million gallons of sewage	1,600	430	190	970	106	2.2	1.7
Parts per million parts of sewage	190	52	23	117	13	.26	.2

As the analysis indicates, this material is not sludge in any sense of the word. It is for the most part clean sand mixed with a considerable amount of coal cinders and small bits of wood, cloth, and pebbles. During the whole period it has been spread upon the grounds of the station immediately surrounding the laboratory and has given no offense.

The figures show only the total and average amounts of detritus collected for the whole period. No accurate data are at hand to show the effect of the seasons on the amount of detritus deposited It may be judged by the frequency with which it was necessary to clean out the chamber that the maximum deposits occurred during the early spring thaws. The Boston city records, already referred to, show that at Moon Island there is a maximum of deposit in March and a second maximum during the summer months. Local conditions of rainfall evidently largely determine the amount of detritus sent into the sewer, but monthly variations from the mean yearly deposit are not as a rule greater than 25 per cent of that value. In the spring of 1904 a large amount of snow was thawed by the warm rains and during ten days 1,600 pounds of detritus were taken from the detritus chamber and from storage tank A, into which some excess of detritus had been carried over; this was about one-third of the total amount removed during the fifteen months of the experiment. The amount of sewage pumped during that time was 100,000 gallons, giving an average of 16,000 pounds of detritus per million gallons of sewage. This may be fairly taken as the maximum for a like period of time, although for shorter periods the rate of deposit might be greater.

The line of demarcation between the so-called detritus and the remaining suspended solids, or sewage sludge proper, is rather sharply marked by the rapidity with which the particles settle. One class of material will settle out in a very few minutes when the velocity is still considerable and the other will settle only when the liquid is practically at rest and in the course of hours rather than minutes. According to figures given by Robinson (1896), a velocity of 0.5 foot per second will not move fine clay and 0.7 foot will just move coarse sand. Hence it may be stated that detritus may be removed from sewage at any velocity less than the former figure. On the other hand, sedimentation of the true suspended sludge necessitates a slackening of velocity to 0.1 foot per second or less. In the London settling basins velocities of 0.07 foot are maintained; at Manchester, 0.05; at Saltley and Sutton, 0.03; and at Frankfurt a. M., 0.01 to 0.02. Steurnagel (1904) found that velocities less than 0.07 foot permitted as complete sedimentation as was possible with absolute rest, but that 0.13 foot was too great. Again, the time required for sedimentation is considerably different in these two classes of material. Detritus, being largely sand, will settle out in a very few minutes; but the remaining solids

require a much longer time for sedimentation. In some experiments on this point in a 40-cm. cylinder the removal of suspended solids by sedimentation was found to be about 25 per cent in five minutes, 50 per cent in thirty minutes, and 75 per cent in twenty-four hours. Steurnagel studied the same phenomenon in a deeper layer (2 meters) and found the removal of suspended organic matter to be 42 per cent in five minutes, 61 per cent in twenty-five minutes, 75 per cent in six hours, and 80 per cent in twenty-four hours.

Whether the suspended organic solids in sewage must be removed by some special process depends largely on the general method of purification. With intermittent filters, if there be ample areas of sand available, crude sewage may be handled without preliminary treatment, as is the case at most of the Massachusetts areas. When, on the other hand, suitable sand is difficult to obtain, it may be advisable to remove the suspended solids as far as possible in order to obtain more rapid rates. With the contact filter it seems probable that some method of sludge removal will be generally necessary in order to maintain the capacity of the beds. With the trickling filter it may often be possible to handle crude sewage without preliminary treatment. If a clear, as well as a nitrified, effluent is desired, however, sedimentation must follow the oxidizing process. Whether the removal of solids should precede or follow filtration in this case must be determined by experiment.

If the organic suspended solids are to be removed from sewage, there is a choice of three different methods—namely, sedimentation, chemical precipitation, and straining. For a comparison of the three methods, experiments at Lawrence furnish some useful data. Table LVIII has been compiled from the annual reports of the Massachusetts State board of health for the years 1893–1903.

TABLE LVIII.—*Effect of various processes of preliminary sewage treatment at Lawrence, Mass. (Massachusetts, 1894–1904).*

[Parts per million.]

Process and material.	Date.	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
		Albuminoid ammonia.			Free ammonia.	
		Total.	In solution.	In suspension.		
Alum precipitation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		2.8	2	.8	30.7	20.9
Hard-coal strainer:						
Sewage	1901–1903	5.5	2.9	2.6	42.1	38.1
Effluent		3	2.1	.9	43.3	23.6
Coke strainer:						
Sewage	June, 1894, to September, 1898.	6.4	2.5	3.9	30.8	38.8
Effluent		3.3	2.3	1	31.8	22.2
Septic tank A:						
Sewage	1901–1903	6.4	2.9	3.5	39.1	47.7
Effluent		3.3	2.1	1.2	36.7	29.4
Sedimentation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		4.2	2.7	1.5	33	30.7

The samples of effluent from chemical precipitation with alum represent the supernatant liquor obtained by treating the sewage with sulphate of alumina at a rate of 1,000 pounds per million gallons and allowing the mixture to settle for four hours in a barrel. The sedimentation experiments were made by settling the sewage for four hours without other treatment. The coke strainer was a layer of coke breeze 6 to 8 inches deep and was operated at a rate of about 1 million gallons per acre per day. The coal strainer was a 12-inch layer of "buckwheat" coal and was run at a rate of approximately 1 million gallons per acre per day. Some septic-tank results for 1900–1903 have been included, the septic tank being considered in this place as a variant of sedimentation. The important conclusion from these experiments is that the results of the various processes are not very dissimilar. The small differences observed are in favor of the chemical-precipitation process, plain sedimentation showing the poorest results.

Martin (1905) has compiled, from the testimony given before the royal sewage commission, figures from various sources relating to the removal of suspended solids by chemical precipitation, septic tanks, and coarse filters. While the coarse filter is not strictly a preliminary treatment for the removal of suspended solids, since it is also a true process of purification, the comparative results obtained by these three processes are of interest in this connection. The average suspended solids in effluents from chemical precipitation plants are, at Kingston 14 parts per million, at Chorley and Richmond from 40 to 70, and at London 112. Similar figures from septic-tank installations are, at Salford 29 to 71, Manchester 100 to 286, Leeds 114 to 143, Burnley 130, Oldham 143, Sheffield 157, Accrington 178, and Birmingham 244. The average suspended solids in coarse-bed effluents are at Sheffield 43 to 57, Sutton 45, Blackburn 60, Aylesbury 111, and Leeds 151 to 196.

In general it is clear that chemical precipitation and straining will produce effluents which as regards suspended solids only are somewhat superior to those from either plain sedimentation or septic treatment. In the case of precipitation the cost of the chemical treatment and the necessary disposal of an increased volume of sludge must be considered. In straining processes sludge is produced in varying quantity according to the conditions under which the strainer is operated. A strainer run at so low a rate that anaerobic processes are carried out within it is practically a septic tank and can be so operated that there is little accumulation of organic matter. Such a strainer is septic tank No. 6 at this station, described on page 124, where it is pointed out that here the tank operates like a simple septic tank, the stone filling playing no important part. Again, with still lower rates and

with resting periods, the strainer becomes practically an oxidizing filter and disposes of considerable sludge in much the same way as does a contact bed. On the other hand, true strainers, run at rapid rates with the object simply to remove suspended solids without destroying them, come in a different class. Their surfaces require constant care, while not only the accumulated sludge itself but that part of the surface which is necessarily removed at the same time must be disposed of. Sedimentation, although it does not give quite such perfect removal, is generally preferable to either of these methods, since it avoids the expense of chemicals and of renewing or treating the surface of strainer beds; it will probably prove in general the most practical and economical process of preliminary treatment for removing fine suspended material.

Under the term sedimentation is included septic treatment, since the septic process is really plain sedimentation with the additional anaerobic fermentation of the sludge produced. Such a process seems to combine the best features of all the preliminary treatments thus far proposed, since it effects an adequate removal of suspended solids with no expense for chemicals and produces a minimum of sludge. Furthermore, the actual removal of suspended solids is somewhat greater with the septic tank than with plain sedimentation, from the solution of particles too small to settle easily. The only disadvantage in septic treatment is that if it be too prolonged changes may be set up which make subsequent treatment difficult. The problem is to combine the maximum liquefying action with the minimum production of toxic substances. If that can be done, the septic tank offers in general the best solution of the problem.

PRELIMINARY TREATMENT IN THE SEPTIC TANK.

It having been assumed that if any preliminary treatment were necessary in the purification of Boston sewage the septic tank would probably furnish the most available method, the next problem was to determine the best conditions under which a septic tank could be operated. In particular, it was desired to compare the efficiency of different periods of storage, the results obtained from open and closed tanks, and the effect of filling a tank with stone in order to increase the amount of surface action.

Tanks Nos. 5, 6, 8, and 10, all closed tanks, were started in June, 1903, and open tanks Nos. 7 and 9 in March, 1904. All were operated continuously until June, 1905. Tank No. 5 was operated for the first six months at a forty-eight hour rate and for the remaining eighteen months at a twelve-hour rate. Tank No. 7 had a twelve-hour period, tanks Nos. 6, 9, and 10 a twenty-four hour period, and

tank No. 8 a forty-eight hour period. In each case the linear distance traveled was about 6 feet and the depth 3 feet, making the

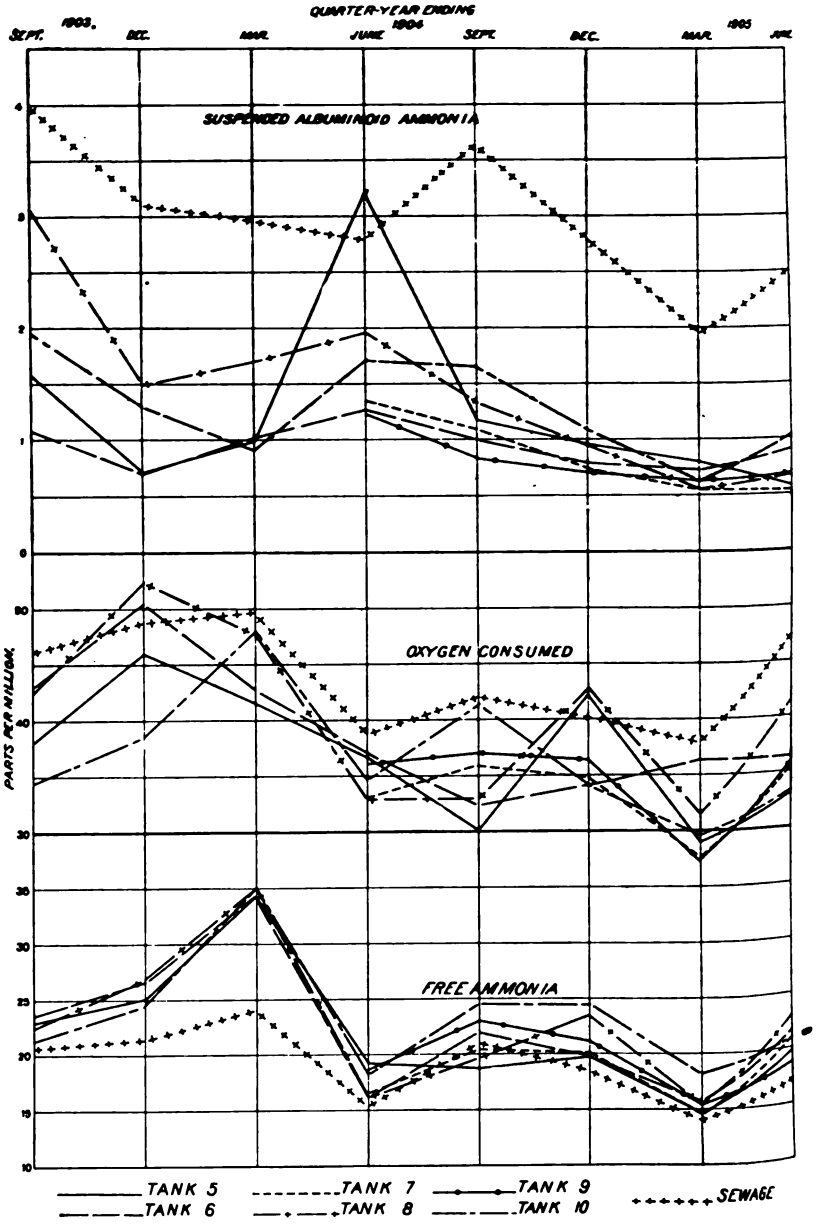


FIG. 16.—Composition of septic effluents.

ratio of l:d equal 2:1. The importance of this factor has recently been pointed out by Hazen (1904). Tank No. 6 was filled with

nch crushed stone. Septic action began in all the tanks very ı after they were started, the effluent being free from gross tur- ity and much darkened. The dark color and offensive odor of e septic effluents are undoubtedly due in part to the formation ulphides from the large amount of sulphates introduced with the water. This phenomenon has been noticed by Clark in the tment of hard waters at Lawrence (Barbour, 1904). Hoppe- ler (1886) believed the reaction to be a direct reduction of cal- n sulphate by methane. It is of some importance, aside from foul odors produced, since it has been found at Burton-upon- ıt that the formation of H_2S has a serious effect on subsequent ification on land (Smith, 1901). Scum formed at first on the ı tanks, but later disintegrated and sank and did not re-form. he closed tanks a scum 1 inch thick was found when they were lly opened.

he most important constituents of the effluents from the various ks are plotted in fig. 16. It will be noticed in the first place that various effluents are much alike in composition. All show a eral improvement during the course of the two years, but this ccounted for rather by the decreasing strength of the sewage ı by increased efficiency. The septic-effluent curves follow the le sewage closely all through, rising in the late autumn of 1903, he summer of 1904, and in the spring of 1905, when the sewage ngthened with diminishing rainfall. In absolute values, oxygen sumed shows a slight decrease in the septic tanks and free ammo- a slight increase. No doubt the reduction in carbonaceous mat- is really considerably greater than it appears, since the septic omposition tends to break up the more stable compounds and eases that proportion of the total carbonaceous matter which is aled by the oxygen-consumed test. The hydrogen sulphide also rferes seriously with the value of this test. The chief difference ween the sewage and septic effluents, aside from the reduction urbidity, appears in the albuminoid ammonia. The nitrogen in form was diminished to from two-thirds to one-half its sewage ıe. The diminution of dissolved albuminoid ammonia was slight distinct, while the suspended portion was reduced to a little r one-third its original amount. The suspended albuminoid nonia is plotted with the total oxygen consumed and free ammo- in fig. 16.

TABLE LIX.—*Quarterly averages of analyses of effluent from septic tanks.*

TANK 5, CLOSED TANK; STORAGE PERIOD, TWELVE HOURS.[a]

Date.	Temperature (° F.).	Analyses (parts per million).						
		Turbidity.	Nitrogen as—				Oxygen consumed.	
			Albuminoid ammonia.			Free ammonia.	Total.	Dissolved.
			Total.	In solution.	In suspension.			
1903-4.								
June to August	68	.....	4.2	2	1.6	22.9	38	.....
September to November	59	.....	3.1	2.4	.7	25	45.9	.....
December to February	48	.....	3.9	2.9	1	34.2	41.3	.....
March to May	52	240	6	2.8	3.2	19	36.5	26.5
Yearly average	58	240	4.1	2.6	1.5	24.3	41.7	26.5
1904-5.								
June to August	67	220	3.8	2.7	1.1	18.7	30.1	23.8
September to November	57	190	3.6	2.6	1	19.6	42.1	34.3
December to February	44	190	3.6	2.8	.8	14.6	28.9	22.9
March to May	46	200	3.2	2.6	.6	19.7	33	28.1
Yearly average	56	200	3.6	2.7	.9	18.1	33.2	26.9
General average	57	200	3.8	2.6	1.2	20.7	36.9	26.9

TANK 6, CLOSED SEPTIC TANK FILLED WITH STONE; STORAGE PERIOD, TWENTY-FOUR HOURS.

1903-4.								
June to August	68	.....	3.7	2.6	1.1	23.5	42.8	.....
September to November	59	.....	2.9	2.2	.7	26.5	50.3	.....
December to February	47	.....	3.6	2.6	1	34.2	42.7	.....
March to May	52	180	4.1	2.9	1.2	16	37	26.2
Yearly average	58	180	3.4	2.5	.9	24.3	44.9	26.2
1904-5.								
June to August	67	170	3.2	2.2	1	21.9	32.4	27.2
September to November	59	190	3.3	2.5	.8	19.6	34	29.7
December to February	44	190	3.9	3.2	.7	15.7	29.6	22.8
March to May	46	160	3.3	2.4	.9	20.8	33.3	24.7
Yearly average	54	180	3.4	2.6	.8	19.5	32.2	26.
General average	57	180	3.4	2.5	.9	21.5	37.8	26

TANK 7, OPEN SEPTIC TANK; STORAGE PERIOD, TWELVE HOURS.

1904-5.								
March to May	52	170	3.9	2.5	1.4	16.5	33.1	26.5
June to August	69	160	2.8	1.7	1.1	20.3	35.8	31.4
September to November	54	170	3.1	2.3	.8	20.1	34.9	31.7
December to February	45	180	3.5	3	.5	14.5	27.7	21.4
March to May	46	190	3.7	3.1	.6	16.8	35.5	29
Yearly average, June to June	56	170	3.2	2.5	.7	17.9	33.2	28.1
General average	55	170	3.4	2.5	.9	17.6	33.2	27.9

TANK 8, CLOSED SEPTIC TANK; STORAGE PERIOD, FORTY-EIGHT HOURS.

1903-4.								
June to August	66	.....	5.6	2.5	3.1	22.4	42.4	.....
September to November	58	.....	3.6	2.1	1.5	26.8	52.3	.....
December to February	47	.....	5	3.3	1.7	35	47.7	.....
March to May	51	230	4.3	2.3	2	16.1	32.8	26.5
Yearly average	57	230	4.3	2.4	1.9	25.1	46.1	26.5
1904-5.								
June to August	67	200	3.7	2.3	1.4	19.5	32.9	26.3
September to November	38	210	3.5	2.5	1	23.5	42.9	35.6
December to February	45	180	3.7	3.1	.6	15.3	31.6	25.1
March to May	45	170	3.5	2.8	.7	23	41.6	33.8
Yearly average	56	190	3.6	2.7	.9	20.5	37.3	30.3
General average	57	190	3.8	2.6	1.2	22.1	40.7	29.9

[a] Before Dec. 7, 1903, 48 hours.

: LIX.—*Quarterly averages of analyses of effluent from septic tanks*—Continued.

NK 9. OPEN SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

Date.	Temperature (° F.).	Analyses (parts per million). Turbidity.	Nitrogen as— Albuminoid ammonia. Total.	In solution.	In suspension.	Free ammonia.	Oxygen consumed. Total.	Dissolved.
1904-5.								
fay	52	170	3.6	2.4	1.2	18.6	36	26.6
igust	68	160	2.7	1.8	.9	22.9	36.9	29.1
to November	55	170	2.9	2.2	.7	21.2	36.3	32.1
to February	45	190	3.6	2.9	.7	15.3	27.3	21.9
fay	46	160	3.9	3.2	.7	18.8	36	29.8
ly average, June to June	56	170	3.2	2.4	.8	19.6	33.7	27.7
ral average	55	170	3.2	2.4	.8	19.4	34.1	27.5

: 10. CLOSED SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

1903-4.								
igust	66	.....	4.5	2.6	1.9	21.3	34.3	.....
to November	58	.....	3.4	2.1	1.3	24.3	38.5	.....
to February	49	.....	3.8	2.9	.9	35	48	.....
fay	51	270	4.2	2.4	1.8	18.2	34.6	26.4
ly average	57	270	3.8	2.4	1.4	23.4	37.9	26.4
1904-5.								
igust	67	190	3.5	1.9	1.6	24.6	41.3	23.2
to November	57	220	3.9	2.8	1.1	24.4	34	23
to February	43	250	3.9	3.2	.7	18.1	36.3	23.6
fay	45	170	3.7	2.7	1	20.8	36.3	27.5
ly average	56	210	3.7	2.6	1.1	21.9	37.3	24.1
ral average	56	210	3.8	2.5	1.3	22.5	37.5	24.5

BLE LX. —*General averages of analyses of crude sewage and septic effluents.*

Material.	Date.	Storage period (hrs.).	Temperature (°F.).	Analyses (parts per million). Turbidity.	Nitrogen as— Albuminoid ammonia. Total.	In solution.	In suspension.	Free ammonia.	Oxygen consumed. Total.	Soluble.
.....	June, 1903, to June, 1905.	.....	59	305	5.9	3	2.9	18.5	43.1	24.4
.....	March, 1904, to June, 1905.	.....	58	305	5.7	3	2.7	17.6	41.5	24.7
om tank No. 5	June, 1903, to June, 1905.	[a]48-12	57	200	3.8	2.6	1.2	20.7	36.9	26.9
om tank No. 6	do	24	57	175	3.4	2.5	.9	21.5	37.8	26
om tank No. 7	March, 1904, to June, 1905.	12	55	170	3.4	2.5	.9	17.6	33.2	27.9
om tank No. 8	June, 1903, to June, 1905.	48	57	190	3.8	2.6	1.2	22.1	40.7	29.9
om tank No. 9	March, 1904, to June, 1905.	24	55	170	3.2	2.4	.8	19.4	34.1	27.5
om tank No. 10	June, 1903, to June, 1905.	24	56	210	3.8	2.5	1.3	22.5	37.5	24.5

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

The average analyses of the effluent from each tank for the whole period of operation, with the average analyses of the sewage for the fifteen-month and the two-year periods, are indicated in Table LX. The figures on the whole show a remarkable uniformity of results for open and closed tanks and for twelve, twenty-four, and forty-eight hour periods. Even the figures for suspended albuminoid ammonia and total oxygen consumed bring out only slight differences. In a comparison of tanks Nos. 5 and 10 (closed) with the corresponding twelve and twenty-four hour open tanks, the open-tank effluents appear to be slightly better. It must be remembered, however, that the open tanks were operated during the last fifteen months only, when the sewage was weaker. This factor being taken into account, the work of the open and closed tanks is practically equal.

With regard to period the figures are no more conclusive. A comparison of tanks Nos. 7 and 9 (open) apparently shows no important difference between the effect of twelve and of twenty-four hours' storage. Similarly, tanks Nos. 5, 8, and 10 (closed) produce almost the same results, although operating with periods varying from twelve to forty-eight hours. Tank No. 6, filled with 1½-inch crushed stone, produces a somewhat greater reduction in suspended albuminoid ammonia than do the other tanks, but the difference is too slight to be of practical importance.

TABLE LXI.—*Analyses of septic-tank contents, including sludge and scum, at close of experiment.*

No. of tank.	Date.	Storage period (hrs.).	Depth of sludge (in.).	Analyses (parts per million).								
				Solids.		Nitrogen as—				Oxygen consumed.		Fats.
				Total.	Loss on ignition.	Free ammonia.	Albuminoid ammonia. Total.	Albuminoid ammonia. Soluble.	Total.	Total.	Soluble.	
5	June, 1903, to June, 1905.	[a]48-12	8.4	17,000	6,580	35	145	10	425	1,000	130	1,590
6	do	24				6	66	10		640	48	3,008
7	March, 1904, to June, 1905.	12	3.3	10,600	3,040	34	42	10	250	680	100	620
8	June, 1903, to June, 1905.	48	8.7	14,900	6,068	50	80	10	400	940	110	870
9	March, 1904, to June, 1905.	24	4.4	12,500	3,912	40	70	7	325	680	110	1,090
10	June, 1903, to June, 1905.	24	5.4	16,900	5,952	50	102	7	400	1,020	100	900

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

When this series of experiments was closed in June, 1905, the inlet and outlet of each tank were closed and the contents, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table LXI. The analyses refer to the total

quid and solid contents of the tank at the time its operation ceased, suspension containing about 98 per cent of water. The sludge was stimated by allowing the mixed tank contents to settle in a cylinder or twenty-four hours and observing the relation between the nick sediment produced and the clear supernatant liquid. The nickness of the sludge (which as measured by this method includes ie scum also) was 3.3 and 4.4 inches for the tanks which had run for teen months and 5.4, 8.4, and 8.7 inches for those which had run for vo years. With regard to total solids the loss on ignition is impor- nt and measures fairly the total storage of organic matter by the ptic tank. This is seen to be from 3,000 to 4,000 parts per million ter fifteen months and about 6,000 parts after two years. The effect the storage period on the accumulation of sludge is striking. As ready shown, the tanks in which the flow was more rapid appear to cercise quite as much purifying power as the slower ones. Since vice as much sewage passed through tank No. 7 as through tank No. and twice as much through tank No. 10 as through tank No. 8, with he production of a comparable effluent, more sludge might be expected a tanks Nos. 7 and 10. We actually find less, which suggests that the lecomposing action of the tank is favored by a shorter storage period. n tank No. 7, with a twelve-hour period, there were 3.3 inches of ludge, corresponding to 0.6 cubic yard per million gallons of sewage passed. In tanks Nos. 5, 9, and 10, with a twenty-four-hour period, he depth of sludge was respectively 8.4, 4.4, and 5.4 inches, equiv- lent to 1.4, 1.7, and 1.5 cubic yards per million gallons. In tank No. 8, with a forty-eight hour period, there were 8.7 inches of sludge, or 1.7 cubic yards per million gallons.

It has been pointed out above that a prolonged septic action dimin- shes the number of bacteria and probably interferes with sludge eduction. Another interesting suggestion, which may help to xplain the results herein recorded, has recently been made by Stod- lart (1905). He finds, in a septic tank of several compartments, a considerable deposit of sludge in the first compartment, giving a airly clear supernatant liquid, which in the last chamber of all under- goes a secondary decomposition, leading to the throwing down of an dditional precipitate of offensive sludge.

From the data in Tables LX and LXI have been calculated, in Table LXII, the actual amounts of certain constituents, which were (*a*) allowed to enter the tanks, (*b*) discharged in the effluents, (*c*) stored in the tanks as sludge and scum, and (*d*) removed by septic decomposition. About 50 pounds of nitrogen as albuminoid ammo- nia per million gallons of sewage entered the tanks. Roughly, 30 pounds were discharged and 20 pounds remained behind, of which 15 to 17 pounds were decomposed. The last columns in the table show the *total volatile solids* and fats stored in the various tanks,

calculated in relation to the sewage treated. These figures bring out very sharply the superior decomposing power of the tanks operated at short periods. Tank No. 7 (twelve hours) and tank No. 5 (twelve hours for the last eighteen months) exhibit the lowest values. Tanks Nos. 9 and 10 (twenty-four-hour period) come next, with 90 and 101 pounds, respectively. Tank No. 8, with its forty-eight-hour storage, gave 206 pounds of stored organic matter per million gallons of sewage treated. The large proportion of fats shown in the last column is notable, amounting to one-fourth or one-eighth of the total stored organic matter.

TABLE LXII.—*Storage and decomposition of organic matter in septic tanks.*

No. of tank.	Flow (gallons).	Storage period (hours).	Nitrogen as albuminoid ammonia.				Solids stored.		Fats stored.
			Entering. (*a*.)	Leaving (*b*.)	Stored. (*c*.)	Decomposed. ($d=a-b-c$.)	Total.	Loss on ignition.	
			Pounds per million gallons of sewage passed.						
5	445,000	[a] 48–12	49.2	31.7	1.3	16.9	1.8	69	16
6	135,000	24	49.2	28.3	[b] 10.1	11.9	.....	.....	101
7	393,000	12	46.7	28.3	.4	18.1	115	35	6
8	133,000	48	49.2	31.7	2.6	15.9	510	206	29
9	197,000	24	46.7	26.7	1.5	17.8	279	90	25
10	266,000	24	49.2	31.7	1.6	17.3	282	101	15

[a] Changed December 7, 1903, from 48 hours to 12 hours.
[b] Estimated from loss of capacity in tank due to sludging up of the space between the stones and from analysis of a sample of the sludge.

Altogether it may be concluded from these experiments that the septic tank will effect a considerable removal of solids from Boston sewage, amounting to about two-fifths of the nitrogen as measured by albuminoid ammonia. Its effluent is free from gross turbidity, but dark and offensive from the liberation of hydrogen sulphide. Of the organic matter retained in the tank, a very large proportion, amounting to well over three-fourths if measured by the albuminoid nitrogen, is decomposed, and the accumulation of stored material in the tank is slight after two years of operation. Apparently such tanks might operate for several years without being cleaned. The covering of tanks is nonessential, since closed and open tanks work equally well. Storage periods varying from twelve to forty-eight hours give similar effluents, but there is an increasing tendency to accumulate sludge as the period is lengthened. The filling of a septic tank with stone is of only slight advantage.

It is believed, therefore, that open tanks with a capacity not exceeding the flow for twelve hours would prove the most favorable preliminary treatment for Boston sewage.

PURIFICATION BY INTERMITTENT SAND FILTRATION.

The early Lawrence experiments indicated pretty clearly what may be effected by intermittent sand filters operating under the most favorable conditions. They showed that a 4 to 5 foot bed

of sand of an effective size of 0.04 to 1.4 mm. would take sewage at rates varying from 0.02 to 0.06 million gallons per acre per day, producing a clear and odorless effluent in which the nitrogenous constituents had been almost entirely converted into the mineral form. In the line of a modification of the process in order to secure more rapid rates than these the only important step has been the installation of preliminary septic tanks, and septic effluent has been treated in the Middle West at rates up to 0.4. Exact data are scarce, however, as to the comparative operation of sand filters with crude sewage and with septic effluent. It was therefore planned, in this investigation, to determine how far the preliminary septic process would be of advantage in the treatment of Boston sewage, and—with or without its use—to what extent the required area of sand could be diminished by the use of rates of filtration over 0.1 million gallons per acre per day. It was desired also to find out how far the depth of sand could be decreased with safety, since this may be an important economic consideration when artificial sand areas must be constructed.

The first sand filters, Nos. 1 and 2, began operation in June, 1903. Both were cypress tanks, 6 by 4 feet by 3 feet deep, underdrained with 6 inches of material ranging from 3-inch stones up to the sand. No. 1 contained, over the underdrain material, two feet, and No. 2 one foot of drift sand with an effective size of 0.17 mm. and a uniformity coefficient of 3.5. Both were started at a rate of 0.1 and so operated until December, 1903. At that time the rate on No. 1 was doubled, while that of No. 2 remained the same in amount but was divided into two daily doses with twelve hours' interval between them. In June, 1904, both rates were doubled, No. 2 receiving 0.2 million gallons per acre per day in two doses and No. 1 receiving 0.4 million gallons per day in four doses. Both filters received crude sewage.

This experiment gave conclusive results as to the minimum depth for a sand filter. While the 2-foot filter worked satisfactorily, No. 2, with half that depth, was a failure. Its effluent was dark and turbid and of an offensive odor. Not one of the samples tested passed the incubator test. The analytical results in Table LXIII show marked variations from time to time, but the free ammonia present was generally from 15 to 20 parts per million—nearly as high a value as that of the crude sewage. The albuminoid ammonia was usually between 2 and 3 parts and the oxygen consumed about 20 parts—in each case about half the sewage value. Nitrates were always low.

The operation of the 2-foot bed, on the other hand, was eminently satisfactory. The effluent was clear and bright and entirely free from turbidity and odor. Every sample tested successfully passed the incubator test and even bacteriologically the effluent appeared well, having an average of 1,220 bacteria per cubic centimeter. The bacterial composition of the various effluents obtained in these experiments

has been fully discussed elsewhere (Winslow, 1905 a). The analytical characters of the effluent from tank No. 1 are given in Table LXIII. The free ammonia once reached 9 parts per million in the summer quarter of 1904, just after the increase in rate, but has been generally under 4 parts. The albuminoid nitrogen has been under 1 part, and the oxygen consumed under 8 parts except in one quarter. The nitrates, on the other hand, have not fallen below 20 parts, indicating a very high degree of purification, and dissolved oxygen has constantly been present. The increase in rate from 0.1 to 0.2, and again from 0.2 to 0.4, did not appreciably alter the quality of the effluent.

The surface of the filter, even at these high rates, has not required excessive care. It was scraped in August, 1903, and November, 1904, and raked once and scraped once in March, 1905. The total material removed in three scrapings during two years of operation amounted to a layer 0.48 inch thick, or 1,600 cubic inches. This is equivalent to 0.36 cubic yard per million gallons of sewage filtered.

Tanks Nos. 24 and 25 were put in operation in March, 1904, in order to compare the treatment of septic effluent with the purification of crude sewage as conducted in tank No. 1. All three were alike in construction. Tanks Nos. 24 and 25 were throughout operated at a rate of 0.4 million gallons per acre per day, taking four daily doses at six-hour intervals. Tank No. 24 received the effluent from tank No. 7, which had been septicized for twelve hours; tank No. 25 that from tank No. 9, which had been septicized for twenty-four hours. The analyses of the effluents from tanks Nos. 24 and 25 are shown in Table LXIII. In each of the three tanks studied the nitrates increased rapidly during the first months of operation (nine months in the case of tank No. 25, six months in the other two cases) and then fell to a somewhat lower value.

Fig. 17 brings out more clearly the relative quality of the three effluents, showing that from tank No. 1, which took crude sewage, to be the best. In the figure the blocks for sewage constituents represent not the septic effluent applied, but the crude sewage before treatment. It will be noticed that the average sewage applied to tank No.1 was stronger than that treated by septic tanks Nos. 7 and 9 and filters Nos. 24 and 25. Nevertheless, the free and albuminoid ammonia values are lower and the nitrates higher after sand filtration alone than after combined septic and sand treatment.

In the condition of the surface, the filters receiving septic effluent showed a slight but distinct advantage. During fifteen months of operation tank No. 25 was raked over twice, in September, 1904, and March, 1905, but not scraped. Tank No. 24 was raked on the same dates and also scraped once in March, 1905. This scraping was rendered necessary by a rather unusual phenomenon, the deposition of a thin layer of finely divided sulphide of iron formed by decomposition

hates in the septic tank. After one removal this layer did not orm. It is probable that experiments extending over a longer might have shown greater advantages in the septic process in n to the permanency of filtering surface.

BLE LXIII.—*Quarterly averages of analyses of effluents from slow sand filters.*

TANK NO. 1, 2 FEET DEEP, TAKING CRUDE SEWAGE.

Date.	Temperature (° F.).	Analyses (parts per million).							
		Color.	Turbidity.	Nitrogen as—				Oxygen consumed.	Oxygen dissolved.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
ugust, 1903	65	0	.....	0.4	4.7	0.17	5.1	3.9	.....
r to November,	57	0	.....	.5	1.9	.67	20.9	3.9	3.5
, 1903, to Febru- 4	39	4	.....	1.5	2.9	.57	41.7	4.5	.....
May, 1904	54	15	.....	.4	2.1	.35	23.5	5.5	9.6
rly average	56	4	.....	.6	2.9	.48	19.6	4.3	5.3
ugust, 1904	67	26	.....	.8	9.3	.27	26.8	8.5	6
r to November,	54	47	.....	.5	3.5	.27	22.3	7.4	5.4
, 1904, to Febru- 5	41	0	.....	.4	3.8	.34	24.7	4.3	8.1
May, 1905	43	8	.....	.8	5.4	.38	22	7.2	5.6
rly average	52	26	.....	.6	5.4	.32	23.9	6.8	6.3
eral average	54	19	.....	.6	4.2	.39	22.3	5.6	6.1

TANK NO. 2, 1 FOOT DEEP, TAKING CRUDE SEWAGE.

ugust, 1903	64	.....	.....	0.2	20	0.18	8.5	11.6	0
r to November,	54	.....	.....	1.9	19.4	.31	3.1	25.8	0
, 1903, to Febru- 4	40	.....	210	1.8	25.3	0	0	35.7	0
May, 1904	54	.....	350	2	20.1	.01	0	17.7	.2
rly average	54	.....	255	1.9	17.6	.20	4.6	21.2	0
ugust, 1904	67	.....	110	2.5	17.6	.55	1.2	17.9	0
r to November,	56	.....	165	3.5	18.3	.33	4.5	25.6	3.5
, 1904, to Febru- 5	42	.....	165	3.5	12.6	.23	2.9	28.3	1.9
May, 1905	44	.....	45	2.8	16.5	.57	2.3	19	0
rly average	54	.....	135	3.2	16.1	.36	2.9	23.7	1.8
eral average	54	.....	170	2.5	16.9	.28	3.5	22.4	.9

TANK NO. 24, TAKING 12-HOUR SEPTIC EFFLUENT.

May, 1904	53	18	.....	1.6	10.4	0.25	0.1	6.8	8.5
ugust, 1904	68	20	0	.5	2.7	.60	19.2	7.1	6.6
r to November,	52	6	5	.8	4.7	.17	28.5	5.4	8.5
, 1904, to Febru- 5	42	18	0	.7	3.9	.14	17.9	6.2	8.8
May, 1905	45	8	0	.6	5	.29	20	7.1	4.8
rly average, June 04, to June, 1905	53	15	0	.6	4	.32	21.3	6.5	7.4
eral average	53	15	0	.8	5	.31	19.9	6.5	7.5

TANK NO. 25, TAKING 24-HOUR SEPTIC EFFLUENT.

May, 1904	53	18	.....	1.6	10.5	0.28	1.5	7.1	4.7
ugust, 1904	68	17	0	.5	4.1	.24	15.7	6.2	5
r to November,	53	20	5	.9	5.6	.10	14.6	7	10.8
, 1904, to Febru- 5	42	53	0	.8	3.2	.12	26.4	4.3	9.3
May, 1905	45	21	0	.7	7.3	.25	18.4	8.5	3.4
rly average, June 04, to June, 1905	54	44	0	.7	4.9	.18	18.8	6.4	7.5
eral average	54	43	0	.9	5.6	.19	16	6.5	7.2

In general, the results obtained indicate that in reducing the depth of a sand filter it is not safe to go below 2 feet. One foot of sand is insufficient to effect purification, while a 2-foot bed may yield admirable results. With regard to the value of preliminary septic treatment of Boston sewage before sand filtration, it appears that effluents from the combined process are slightly inferior to those obtained by the sand process alone, while the care of the surface is more difficult when crude sewage is treated. These experiments, it is believed, suggest that it may be possible to treat crude sewage by sand filtration

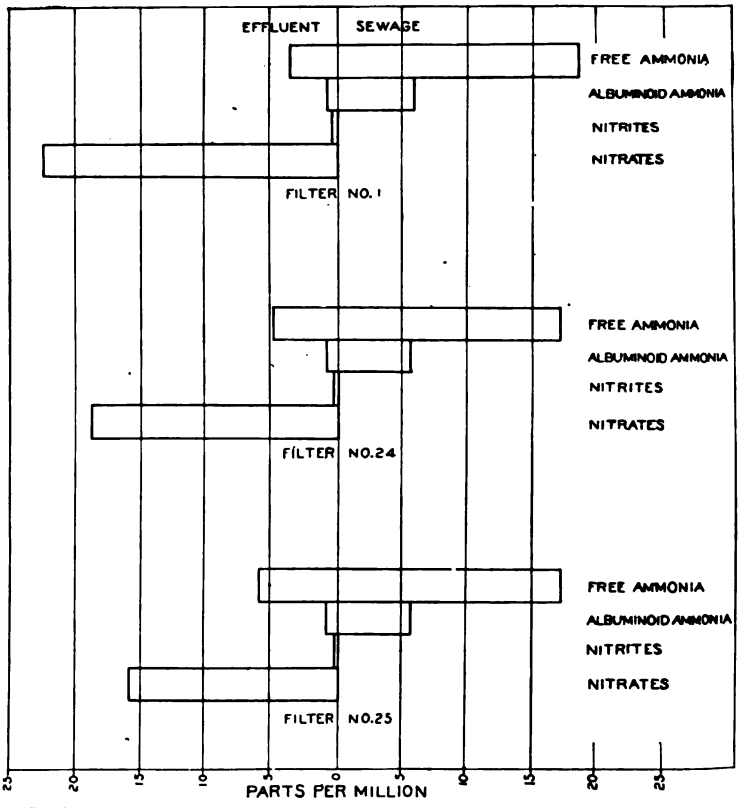


FIG. 17.—Comparison of various forms of nitrogen in crude sewage and sand-filter effluents.

at higher rates than have heretofore been recommended. The operation of filter beds under practical conditions is of course more difficult than in small-scale experiments. In the first place the distribution on large beds is often incomplete, while it is easy in small tanks to obtain perfect distribution. Again, the effect of winter weather was minimized in these experiments. It will be noticed in the tables that the quarterly temperature averages for the sand-filter effluents did not fall below 39° F. In order to estimate the actual importance of this point in outdoor filters, the ratios which the values of free and

lbuminoid ammonia, oxygen consumed, and nitrates for each month ear to the yearly average at Lawrence and Brockton have been calılated and are given in Table LXIV.

ABLE LXIV.—*Monthly variations in sand-filter effluents at Brockton and Lawrence, Mass.*

[Yearly average=100.]

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
FREE AMMONIA.												
rockton	100	163	192	171	134	92	79	63	50	50	50	83
awrence	213	269	204	168	84	48	16	6	8	14	32	120
ALBUMINOID AMMONIA.												
rockton	87	130	130	174	87	87	87	87	87	87	87	87
awrence	175	171	150	132	92	76	67	58	62	49	62	117
NITRATES.												
rockton	85	70	67	81	90	112	118	115	133	129	110	96
awrence	48	38	59	100	139	140	120	116	128	125	109	75
OXYGEN CONSUMED.												
rockton	84	132	152	178	100	84	72	68	68	84	92	108
awrence	170	167	149	122	84	70	69	61	62	64	61	124

The Lawrence figures are the averages of the ratios for tanks Nos. 1, , 3, 4, 6, and 10, from 1895 to 1900, calculated from Clark's analyses 1896–1901). For Brockton the figures used cover the period 1897) 1904 (Brockton, 1898–1905). A regular seasonal variation is indiated, the organic constitutents reaching their maximum in February ith the small Lawrence tanks and in March with the large Brockton lter. The nitrates show a reciprocal curve, being lowest in February. he maximum monthly deviation amounts to about 100 per cent, e worst monthly averages being twice as high as the average in rganic matter. This probably furnishes a fair measure of the mount of damage to effluents by winter weather.

The interference with the surface of the beds by winter weather is uch more serious, and the treatment of crude sewage by intermitent sand filtration at a rate of 0.4 million gallons per acre per day an not be recommended. It is believed, however, that experiments ut of doors and on a larger scale are well worth making in order to ee if the common rates of 0.06 to 0.1 can not be somewhat increased. No doubt beds operated at higher rates will require more attention aid to their surfaces, but it is a question if the raking and scraping ncident to the filtration of a given volume of sewage will be increased y filtering it through a smaller area. It seems probable that the

stable material deposited on the surface of a sand filter bears a fixed ratio to the amount of sewage filtered; the same thing is very likely true of the fatty material which, as Clark has pointed out, penetrates below the surface and gradually decreases the efficiency of an old sand bed. These inevitable deposits will not be increased by higher rates, but will be simply concentrated on a smaller area, while the oxidizable organic material can apparently be nitrified under proper conditions at considerably higher rates than 0.1. The difficulty of scraping during severe winter weather will probably furnish the most serious obstacle to increased rates of filtration.

As a rule, sand filters have been constructed without special care and operated at haphazard. As this process comes into competition with the more elaborate modern methods, it is evidently worth while to see what can be done by applying to it the same expert care which is understood to be required by a contact or a trickling filter. For example, the difficulty of distribution may largely be overcome on a practical scale by careful grading and the use of proper distributors, if it is clear that this is worth doing. The division of the entire daily dose into three or four portions, applied at equal intervals during the twenty-four hours, is an expedient which would certainly largely increase the capacity of any of the Massachusetts beds now operated on the principle of daily or even less frequent dosing. This could be accomplished by the use of automatic devices, as at Wauwatosa and other plants in the Middle West. It has been tacitly assumed that the good results obtained at these filtration areas were wholly due to the preliminary treatment of the sewage in the septic tank. It is possible that they may be in part the result of careful operation and the application of several doses during the twenty-four hours.

PURIFICATION IN CONTACT BEDS OF COARSE MATERIAL.

The experiments at this station on the contact bed were planned to bring out the influence on the results of the treatment of each of the following points: Size and kind of filling material; depth of material; double and single contact process; treatment of crude and septic sewage; and rate of operation. The filters themselves have already been described in full detail (pp. 103–105). For convenience of reference, however, the main facts concerning the filter and its operation will be restated in each case.

Of the seven primary contact beds all are 4 feet square in area. Tanks Nos. 11, 12, 13, 14, and 16 are each 6 feet deep, and Nos. 18 and 20 are each 4 feet deep.

In all cases the method of operation was as follows: The bed was filled during the course of an hour, allowed a two hours' contact, *emptied* in about half or three-quarters of an hour, and allowed to *stand empty* until the next filling. The filling was in all cases con-

nuous, and after the first six months two or more fillings of the ank per day were evenly distributed over the twenty-four hours.

Tanks Nos. 11, 12, 13, and 14 were run alike throughout the experiments. During July and August, 1903, they received one filling per ay. The rate was doubled August 31, 1903, increased to four fillings January 1, 1904, and reduced to three fillings June 24, 1904. During the whole period after August, 1903, tank No. 16, the counterpart of No. 13, was run at three fillings. Owing to the superior esults obtained from tank No. 16 at three fillings over tank No. 13 two the rate of the first four filters was increased to four fillings. his, after a fair trial, was found to be excessive, and the rate of three llings per day was adopted as the most favorable.

Tank No. 11 was filled with coke about 2 inches in diameter. During the period from June, 1903, to June, 1905, it was run at an average rate of 1.8. No material was removed from the surface during e experiment and no serious clogging occurred. The effluent as a le was turbid and putrescible and not satisfactorily purified.

Tank No. 12 was filled with crushed stone 1 inch to 1½ inches in iameter. During the two-year period it was run at an average rate f 1.4. No material was removed from the surface, although toward e end of the period a considerable deposit had accumulated, which ould have required removal in a short time. The quality of the ffluent improved steadily during the second year and was at its best t the conclusion of the experiment. During the spring of 1905 the ffluent generally passed the incubator test. The purification ffected by this filter was largely due to the straining action of the udge layer on its surface.

Tank No. 13 was filled with crushed stone one-fourth to one-half ch in diameter. It was run throughout the two-year period at an verage rate of 1.2. April 6, 1904, ten months after starting this lter, it was necessary to remove a 2-inch layer of deposit from the rface. This material was earthy in appearance and odor, and was sily removed without appreciably disturbing the stones. The ogging material extended to a depth of a few inches within the bed, ut below the surface of the stones was not disturbed. The total eight of the substance removed was 26 pounds; its composition on alysis was as follows: Moisture, 41 per cent; loss on ignition, 6.9 er cent; organic nitrogen, 0.1 per cent. March 21, 1905, 2 inches mixed deposit and filter material were removed. The material of e filter was clogged badly to a depth of 6 inches, below which the ones were clean. This material was similar to that first removed d was not analyzed, except that the stones were separated from the eposit in a sample of the mixture. The total weight removed was 41 pounds, of which 56 per cent, or 79 pounds, was deposit. The fluent from this filter has been uniformly good and those incubator

tests which were made on it showed it to be always nonputrescible. Here still more than with tank No. 12 the straining effect of the surface deposit played an important part.

Filter No. 14 was filled originally with crushed stone one-half to 1 inch in diameter. During the year of its operation, from July, 1903, to June, 1904, it received sewage at an average rate of 1.4. No material was removed from its surface, although at the end of the year there was a considerable accumulation of deposit. The effluent was at all times intermediate between those of No. 12 (1½-inch stone) and No. 13 (one-half inch stone). At the end of the first year the filter was discontinued to make room for an experiment with a brick filter, No. 14A, on the plan of Dibdin's multiple-surface bed, the construction of which has already been described (p. 105). This filter was run throughout the second year at an average rate of 2. No material has accumulated on the surface, owing to the very open construction. The effluent of the filter has been uniformly turbid and putrefactive.

Filter No. 16 is exactly like No. 13, and was planned originally to run parallel with it except as to rate, in order to study the effect of two different rates under otherwise like conditions. As already stated, it was concluded from the work of this filter that three fillings per day were better than two and later that three were better than four. This point having been established the filter was used for experiments of a special character, the results of which have already been published (Phelps and Farrell, 1905). During the second year it was run like No. 13 in all respects. Tank No. 16, however, was not cleaned at the beginning of the second year, and therefore effected a somewhat higher purification from its greater straining action. Its average rate was 1.6.

Tanks Nos. 19 and 20 are each 4 feet deep and filled with crushed stone 1 inch to 1½ inches in diameter. They were run from June, 1903, to January 1, 1904, with two fillings per day. From January 1, 1904, to the conclusion of the experiments they were given three fillings per day. In all respects they were run as nearly alike as possible, No. 19 receiving septic sewage from septic tank No. 10 (thirty hours old) and No. 20 receiving crude sewage. The effluents from these filters were treated on secondary tanks Nos. 17 and 18, respectively. The purification by No. 19, which took septic sewage, has never been satisfactory, the effluent being at all times foul and dark colored and generally putrescible. The effluent of No. 20 has been much more satisfactory from the start. It is also a striking fact that the effluent from No. 20 has been fully as good as that from the fine-stone filters Nos. 13 and 16, and always superior to that from No. 12, from which it differs only in depth and in its consequent lower rate-

Capacity measurements were made on each bed once a week by discharging the effluent into a measuring tank as described above (p. 106). The average results by quarters are brought together in Table LXV. The results are all expressed in percentages of the total cubic capacity of the empty tank. The initial liquid capacity varied from 39 to 48 per cent, the highest values of course being found in the brick and coke beds. The single-contact beds taking crude sewage all decreased in capacity rather steadily, reaching a final value after two years of 26 to 33 per cent. The figures do not furnish evidence that the falling off had reached its limit, as was shown at Manchester. The Dibdin brick filter still showed 40 per cent of open space after one year of operation. The capacity of tank No. 19, which received septic effluent, was maintained at 38 per cent, and the secondary beds, Nos. 17 and 18, retained a capacity of over 35 per cent. The capacity of tank No. 20, which had fallen from 41 to 26 per cent in two years, was measured in August, 1905, after three months of rest, and had risen to 32 per cent.

TABLE LXV.—*Capacity of contact filter, by quarters.*

[Percentage of cubic capacity of empty tank.]

No. of filter.	Initial.	1903–4.				1904–5.			
11	46	.....	44	41	39	38	38	35	32
12	40	37	.....	35	33	33	32	31	30
13	44	37	.....	36	36	35	34	.....	33
14A	48	.....	.....	.....	.....	48	47	47	40
16	42	34	.....	30	.....	.....	.....	31	30
17	39	36	.....	34	37	37	37	.....	35
18	42	.....	37	36	38	38	37	.....	37
19	41	40	.....	.....	39	39	38	.....	.....
20	41	39	37	.....	33	32	31	.....	26

It is necessary to distinguish clearly between the surface clogging, due to the accumulation of material on the surface of the bed, and the true loss of capacity which affects the lower part of the filter. Since in these capacity measurements the tank was always filled just to the original surface of the stones, the former phenomenon in no way affects the results. The surface clogging depends directly on the size of material used, being greatest with the fine beds. In the present experiments it was necessary to clean the one-half-inch stone beds once a year, while the 1½-inch beds were just clogging so seriously as to render cleaning necessary at the end of the second year. The surface layer does not extend more than a few inches into the bed, and its removal is a simple matter which could be managed as easily as the scraping of a sand filter. It must, however, be reckoned with in the cost of operation.

The true loss of capacity, on the other hand, affected tanks Nos. 11, 12, 13, and 16 about equally, amounting in each case to a reduction of about *one-fourth of* the original open space. The ratio of the final

to the initial capacity was 70 per cent for No. 11, 75 per cent for No. 12, 75 per cent for No. 13, and 71 per cent for No. 16. Tank No. 20 showed a greater reduction, to 63 per cent of its original capacity, probably because the material carried into the interstices is proportionately greater with a shallow bed. On the other hand, the secondary beds lost only about one-tenth of their open space, the ratio of final to initial capacity being 90 per cent for No. 17 and 88 per cent each for Nos. 18 and 19. The primary bed taking septic effluent lost only 7 per cent of its original capacity in twenty months of operation.

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents.*

TANK NO. 11, PRIMARY-CONTACT BED OF 2-INCH COKE.

Date.	Temperature (°F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.	
			Total.	In solution.	In suspension.						
June to August, 1903	67	.....	4.2	2.7	1.5	30.8	0.07	0	23.8	.....	0
September to November, 1903	60	.....	3.1	2.3	.8	23.6	.44	0	28.8	.....	0
December, 1903, to February, 1904	45	.....	4.4	3.3	1.1	30.3	.40	0	30.7	.....	0
March to May, 1904	52	150	3.6	2.1	1.5	13.8	.06	0	20.5	18.2	0
Yearly average	57	150	3.7	2.5	1.2	23.1	.24	0	25.7	18.2	0
June to August, 1904	69	160	2.7	1.8	.9	19.3	.25	0	23.7	20.1	0
September to November, 1904	59	120	3.1	2.1	1	14.5	1.60	5	20.6	15.9	.4
December, 1904, to February, 1905	44	90	2.4	1.7	.7	14	.30	1.3	15.6	11.4	2
March to May, 1905	43	140	2.8	2.1	.7	13.8	.35	1.2	16.7	13.2	.5
Yearly average	57	130	2.8	1.9	.9	15.4	.61	1.9	19.1	15.2	.7
General average	57	130	3.2	2.2	1	18.9	.45	1.1	22.1	15.5	.5

TANK NO. 12, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

June to August, 1903	67	.....	4.6	2.9	1.7	20.4	0.01	0	30.9	.....	0
September to November, 1903	60	.....	3.3	2.4	.9	25.5	.66	0	40.6	.....	0
December, 1903, to February, 1904	46	.....	3.6	2.5	1.1	24.3	1.25	0	32	.....	0
March to May, 1904	52	120	3.2	1.9	1.3	9.9	.02	0	22	19.2	0
Yearly average	57	120	3.7	2.5	1.2	20.6	.41	0	32.7	19.2	0
June to August, 1904	69	210	3	1.9	1.1	20.7	.02	0	28.7	22.8	0
September to November, 1904	59	140	3.3	2.1	1.2	15.9	1.43	2.3	21.4	14.9	0
December, 1904, to February, 1905	45	110	3	2	1	15.4	.30	1.5	18.1	15.2	.7
March to May, 1905	44	80	2.1	1.6	.5	11	.68	3.7	14.4	12	1.8
Yearly average	56	130	2.8	1.9	.9	15.4	.61	1.9	20.1	15.9	.6
General average	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4

TANK NO. 13, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE

June to August, 1903	68	.....	4.5	2.8	1.7	19.1	1.03	0	20.7	.....	0
September to November, 1903	60	.....	1.8	1.3	.5	12.7	1.33	3.5	21	.....	.4
December, 1903, to February, 1904	45	.....	1.7	1.3	.4	16.8	.47	1.3	14	.....	0
March to May, 1904	52	70	1.9	1.3	.6	7.3	.36	5	12.3	11.2	.1
Yearly average	57	70	2.5	1.7	.8	13.6	.98	2.2	18.2	11.2	.3
June to August, 1904	68	90	1.6	1.2	.4	12.9	.18	1.9	16.6	13.7	0
September to November, 1904	59	70	1.6	1.2	.4	11.2	.73	15	11.9	9.5	2.1
December, 1904, to February, 1905	44	30	1.7	1.6	.1	5.7	.51	12.3	7.4	6.4	3.5
March to May, 1905	41	40	1.2	1.1	.1	6	.48	8.1	9.4	8.7	.7
Yearly average	56	60	1.5	1.3	.2	8.9	.46	9.5	11.3	9.6	1.5
General average	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4

LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

[K NO. 14, PRIMARY-CONTACT BED OF ONE-HALF TO 1 INCH STONE.

Date.	Temperature (°F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
			Total.	In solution.	In suspension.				Total.	Soluble.	
gust, 1903	67	.....	4.9	3	1.9	19.9	0.03	0	32	.....	.....
to November, 1903	60	.....	2.9	2.2	.7	24	.89	0	31.8	.....	0
903, to February, 1904	45	.....	3.4	2.3	1.1	22.5	.87	0	31	.....	0
ay, 1904	51	160	3.3	2.1	1.2	11.4	.13	.8	16.3	14	2.5
y average	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4

TANK NO. 14A, PRIMARY-CONTACT BED OF BRICK.

gust, 1904	68	250	4.1	2.5	1.6	18.1	0.09	0.1	31	21.8	0.1
to November, 1904	59	190	4.7	2.5	2.2	16.2	.27	.6	25.1	18.6	1.6
904, to February, 1905	45	170	3.3	2.5	.8	14.8	.25	.7	25.8	21	3.7
ay, 1905	43	180	3.5	2.1	1.4	16.4	.23	.2	27.7	19.9	.2
y average	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4

. 16, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

gust, 1903	67	.....	3.7	2.7	1	16.4	1.08	0	20	.....	0
to November, 1903	61	.....	1.9	1.4	.5	11.8	.85	0	16.8	.....	.7
903, to February, 1904	51	.....	2	1.2	.8	23.5	1.50	0	15	.....	0
ay, 1904	54	70	1.8	1.2	.6	5.9	.60	1	14.3	12.2	.3
y average	60	70	2.2	1.6	.6	12.4	.90	.1	16.5	12.2	.6
gust, 1904	69	90	1.6	1.3	.3	6.6	1.34	5.2	13.4	11.3	1.2
to November, 1904	58	90	1.6	1.3	.3	5.6	.63	27.4	11.7	10.3	1.7
904, to February, 1905	45	50	1.3	1.1	.2	3.9	.46	11.1	7.8	7	2.3
ay, 1905	.....	20	1	.9	.1	4.7	.38	8	7.5	7	0
y average	57	70	1.4	1.2	.2	5.2	.78	13.1	10.4	9.1	1.6
al average	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3

17, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

gust, 1903	66	.....	3.1	2.1	1	20.3	1.37	0	22.3	.....	0
to November, 1903	56	.....	2.5	1.9	.6	21.3	3.38	0	24.5	.....	0
903, to February, 1904	49	.....	2.3	1.9	.4	28.8	0	0	18.5	.....	0
ay, 1904	51	70	3.1	2.1	.9	13.6	.07	0	16.8	13.8	0
y average	55	70	2.7	1.9	.8	19.7	.42	0	21.6	13.8	0
gust, 1904	67	90	2	1.5	.5	14.3	.16	2	13.9	11.5	.3
to November, 1904	66	50	1.3	1.1	.2	13.5	.75	8.9	11.3	10.4	.9
904, to February, 1905	43	100	2.3	1.9	.4	12.1	.28	5	14.8	12.9	1
ay, 1905	.....	90	2	1.6	.4	9.2	.02	1.6	12.8	9.5	1
y average	55	80	1.9	1.5	.5	12.4	.31	6	13.3	11.2	.8
al average	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6

18, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

gust, 1903	67	.....	3.5	2.4	1.1	18.4	0.30	0	20.4	.....	0
to November, 1903	62	.....	2.1	1.3	.8	15.2	.43	0	22.8	.....	0
903, to February, 1904	49	.....	2.6	1.8	.8	17.5	.63	0	14	.....	0
ay, 1904	58	80	2.8	1.7	1.1	12.9	.08	.4	17.2	14	.6
y average	61	80	2.6	1.7	.9	15.8	.34	.1	19.8	14	.2
gust, 1904	66	110	2.5	1.6	.9	12.9	.33	1.9	16.6	13.3	.8
to November, 1904	57	90	1.9	1.4	.5	9	2.23	12.1	15.9	14.9	1.7
904, to February, 1905	45	70	1.2	1.1	.1	4.6	.13	15.9	10.6	10.1	2.3
ay, 1905	.....	60	1.3	.9	.4	6.5	1.26	10	10	9.3	2.4
y average	54	80	1.7	1.3	.4	8.1	.89	12.1	13.4	10.7	1.7
al average	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

TANK NO. 19, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE TAKING SEPTIC EFFLUENT.

Date.	Temperature (° F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
			Total.	In solution.	In suspension.				Total.	Soluble.	
June to August, 1903	65	.....	3.5	2.6	0.9	20.8	0.08	0	32	.....	0
September to November, 1903	57	.....	3.1	2.4	.7	24.6	.38	0	31	.....	0
December, 1903, to February, 1904	47	.....	3.3	1.6	1.7	42.5	0	0	36.5	.....	0
March to May, 1904	52	130	2.9	2.1	.8	11.2	0	0	25.8	20.2	0
Yearly average	56	130	3.2	2.3	.9	22	.21	0	30.4	20.2	0
June to August, 1904	67	140	3.1	1.8	1.3	25.5	.17	.8	29.1	21.6	0
September to November, 1904	57	170	3.4	1.7	1.7	17.5	.62	2.3	23.6	16.3	0
December, 1904, to February, 1905	43	150	3.8	2.5	1.3	16.9	.09	1.4	23.4	18.5	1.3
March to May, 1905	.....	190	3.5	2.8	.7	19.8	0	0	30	17.4	0
Yearly average	56	160	3.5	2.2	1.3	20.1	.22	1.2	26.3	18.7	.6
General average	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4

TANK NO. 20, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

June to August, 1903	67	.....	5.7	4.4	1.3	20.4	0.12	0	29.7	.....	0
September to November, 1903	60	.....	3.9	2.7	1.2	17	.40	0	25.2	.....	0
December, 1903, to February, 1904	51	.....	4.7	3.1	1.6	23	.05	0	32	.....	0
March to May, 1904	56	130	3.7	2	1.7	16.9	.08	0	24	17.6	.6
Yearly average	59	130	4.3	3	1.3	18.4	.23	0	26.7	17.6	.1
June to August, 1904	68	150	3.8	2.3	1.5	16.9	.07	.7	23.4	17.1	.2
September to November, 1904	57	140	3.5	2.3	1.2	16.1	2.05	7.6	20.3	16.4	.8
December, 1904, to February, 1905	46	100	2.4	1.8	.6	7.5	.33	9.3	15.3	13.5	2.2
March to May, 1905	.....	110	2.7	2	.7	12.6	.30	2.3	15.8	12.8	2.9
Yearly average	55	120	3	2.1	.9	12.7	.74	6.1	18.6	15	1.3
General average	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8

No. of tank.	Date.	Material.	Size of material (inches).	Average rate (million gallons per acre per day).	Temperature (° F.).	Analyses (parts per million).										Capacity (per cent of cubic contents).	
						Turbidity.	Nitrogen as—						Oxygen consumed		Oxygen dissolved.		
							Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.		Initial.	Final.
							Total.	In solution.	In suspension.								
11	June, 1903, to June, 1905	Coke	2	1.8	57	130	3.2	2.2	1	18.9	0.45	1.1	22.1	15.5	0.5	46	32
12	do	Stone	1-1½	1.4	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4	40	30
13	do	do	½-¾	1.2	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4	44	33
14	June, 1903, to June, 1904	do	½-1	1.4	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4	42	.....
14A	June, 1904, to June, 1905	Brick	.....	2	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4	48	40
16	June, 1903, to June, 1905	Stone	¼-½	1.2	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3	42	30
17[a]	do	do	¼-½	1.2	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6	39	35
18[a]	do	do	¼-½	1.1	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3	42	37
19[b]	do	do	1-1½	1.2	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4	41	38
20	do	do	1-1½	1.1	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8	41	26

[a] Secondary-contact bed.

[b] Septic effluent applied.

The quarterly analyses of the effluents from the several contact beds are given in Table LXVI, and the average analyses for each bed for the whole period of operation are brought together in Table LXVII. An inspection of the latter table and of figs. 18 to 22 will bring out the comparative results attained with filling of different material and different size, with different depths of beds, with different rates of operation, with single and double contact beds, and with the treatment of crude and septic sewage.

First, as to the kind of filling material, it was desired to see if the particularly favorable results reported with the use of coke at London would be obtained with Boston sewage. Tank No. 11, filled with 2-inch coke, is fairly comparable with tank No. 12, filled with 1½-inch broken stone. The initial capacity of No. 11 was considerably higher than that of No. 12 (46 per cent against 40 per cent), and it decreased much more slowly, so that the rate on No. 11 was higher than on No. 12 with the same number of fillings. As clogging occurred in tank No. 12 during the last year of operation, its effluent improved and at the end was much better than that of No. 11. A comparison of the average analyses for the whole period, however, shows that the effluent of No. 11 was slightly better than that of No. 12, in spite of the larger size of material and the higher rate. Thus it appears that coke is somewhat superior to stone.

On the more important question of the size of material, a comparison of tanks Nos. 12 (1½-inch stone), 13 (one-half-inch stone), and 14 (1-inch stone) is instructive. The average analyses given in Table LXVII are not comparable, because tank No. 14 was operated under the conditions mentioned for one year only, and during that year the applied sewage was strongest. In fig. 18, however, the quarterly values may fairly be compared.

As might be expected, both efficiency and clogging increase as the size of the material used diminishes. Tank No. 13 gave a better effluent than tank No. 14; No. 14 a better effluent than No. 12. The effluents from the 1-inch and 1½-inch stone were never of satisfactory quality, except, in the latter case, at the very end of the experiment, while that from the one-half-inch stone was almost always clear and nonputrescible. The efficiency with half-inch material was reached, however, only at the expense of a serious clogging which necessitated the removal of 4 inches of sludge from the surface during two years of operation, leaving the body of the filter for some distance below the surface still badly clogged. These results correspond with those obtained by Dunbar and other German investigators (Dunbar and Thumm, 1902). They show that with beds of fine material a good effluent may be obtained by a single contact, but at the cost of such clogging as to necessitate somewhat frequent removal of the upper

n of the bed. Even the 1½-inch stone showed some clogging wo years, and with such coarse filling a single contact will not, rse, produce a stable effluent.

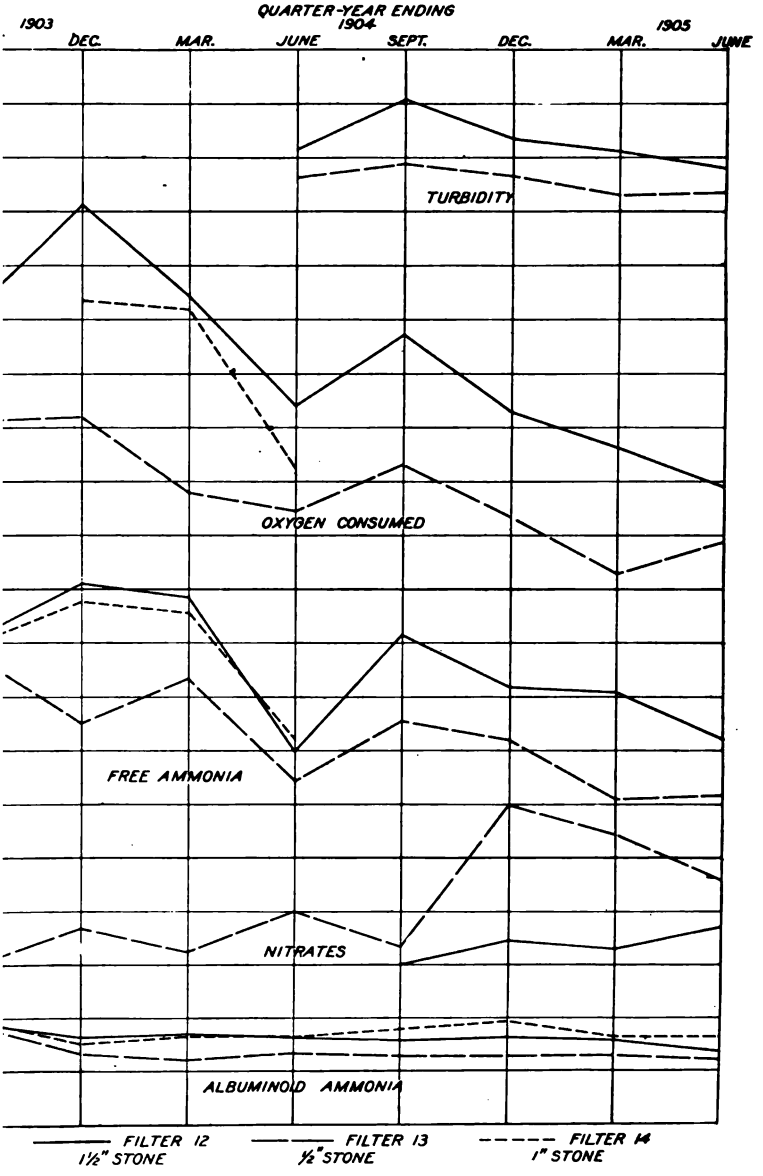


FIG 18.—Comparison of effluents from primary-contact beds of various-sized stone.

k No. 14A, constructed on Dibdin's plan of multiple-surface t (Dibdin, 1904), represents a logical outcome of the desire to permanence by increasing the size of the material. It was filled,

as described above, with bricks laid in regular tiers with the largest obtainable open space, doing away as far as possible with all straining action. Its original capacity of 48 per cent fell in a year only to 40 per cent, and with three fillings a day gave a rate of 2 to 50 per cent higher than was obtained with any other filters similarly operated, with the exception of the coke bed. Its effluent compares favorably with that from tanks Nos. 11, 12, and 14, with the exception of its higher turbidity. It will be noticed that a general improvement in the character of all the effluents took place during the whole period and that it was considerably greater than can be accounted for by the weaker sewage of the second year. This improvement was manifest in all the contact beds to a greater or less degree, and is no doubt in part, but only in part, accounted for by the straining action which accompanies progressive clogging.

The percentages of albuminoid ammonia and of oxygen consumed removed by each filter during each year have been calculated, and the increase in the figures in the second year as compared with the first is shown in Table LXVIII, expressed as per cent of the first-year value. The anomalous results obtained with tanks Nos. 17 and 19 are due to the very low efficiency of No. 17 during the first year and to a deterioration of No. 19, probably due to the overseptic effluent with which it was dosed.

TABLE LXVIII.—*Improvement in percentage efficiency of contact filters in second year of operation.*

[Per cent of first-year value.]

No. of tank.	Albuminoid ammonia.	Oxygen consumed.
11	20	40
12	25	83
13	24	23
16	18	17
17	20.8	71
18	18	13
19	19	9
20	45	32

Data bearing on the effect of contact beds of different depths may be obtained by comparison of tanks Nos. 12 and 20. Both were filled with 1½-inch stone and dosed with three fillings of crude sewage per day. The depth was 6 feet for tank No. 12 and 4 feet for No. 20. The analyses of the representative effluents are shown in fig. 19. It is apparent that the results of treatment in the 4-foot bed are consistently better than in the 6-foot bed. In particular, it will be noticed in Table LXVI that the nitrification is more complete in the shallow filter, but the difference is scarcely great enough to compensate for the diminished rate.

With regard to the rate of operation it has been found, as stated above, that three daily fillings give the most satisfactory results.

tween August, 1903, and January, 1904, tanks Nos. 13 and 16, erwise similar in all respects, were operated with two and three ly fillings, respectively. Tank No. 16, with three fillings, gave the t effluent, as indicated in fig. 20. In January, 1904, the rate on k No. 13 was doubled to four fillings. During the next few nths, while the effluent from tank No. 16 was steadily improving,

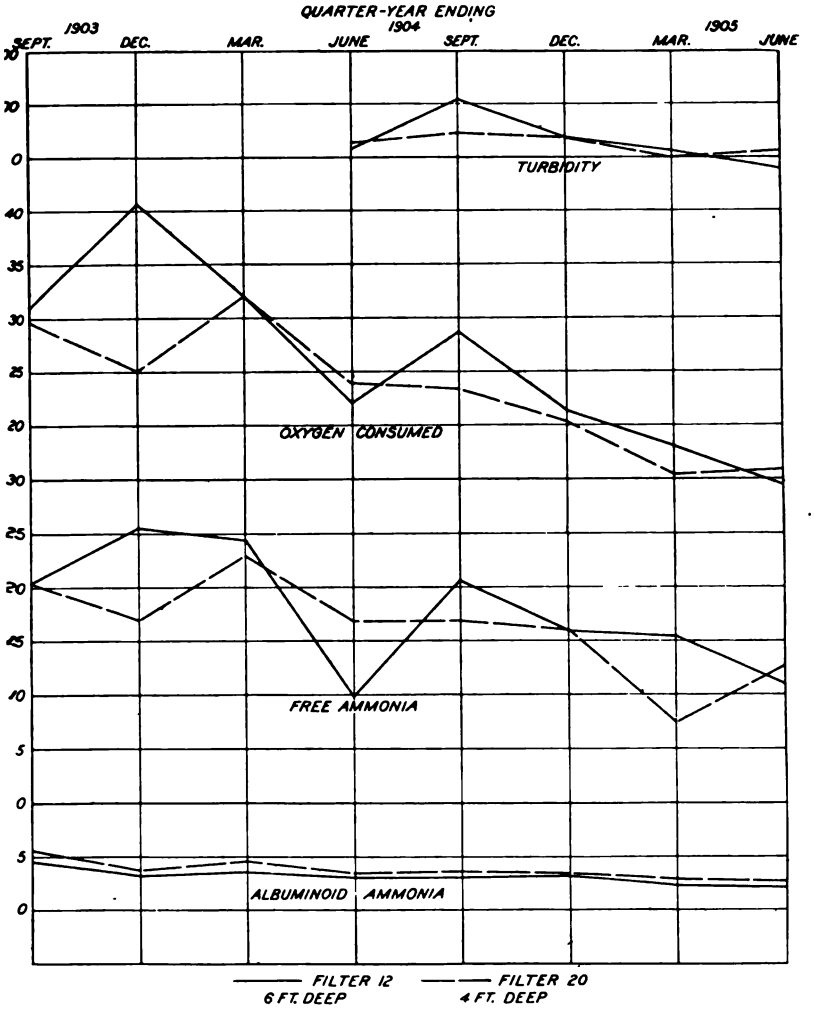


FIG. 19.—Comparison of effluents from primary-contact beds of different depths.

t from tank No. 13 deteriorated. Apparently two fillings are ufficient to maintain the maximum efficiency of the purifying anisms in the bed, while four fillings put a somewhat undue strain their powers. After June, 1904, both beds were operated with ee fillings and gave approximately the same results. Those from

tank No. 16 were a little better, probably because its surface was not cleaned and a considerable straining effect was exerted.

A comparison of the operation of tanks Nos. 19 and 20 furnishes interesting results with respect to the value of preliminary septic treatment. Both were 4-foot beds of 1½-inch stone, receiving, first, two

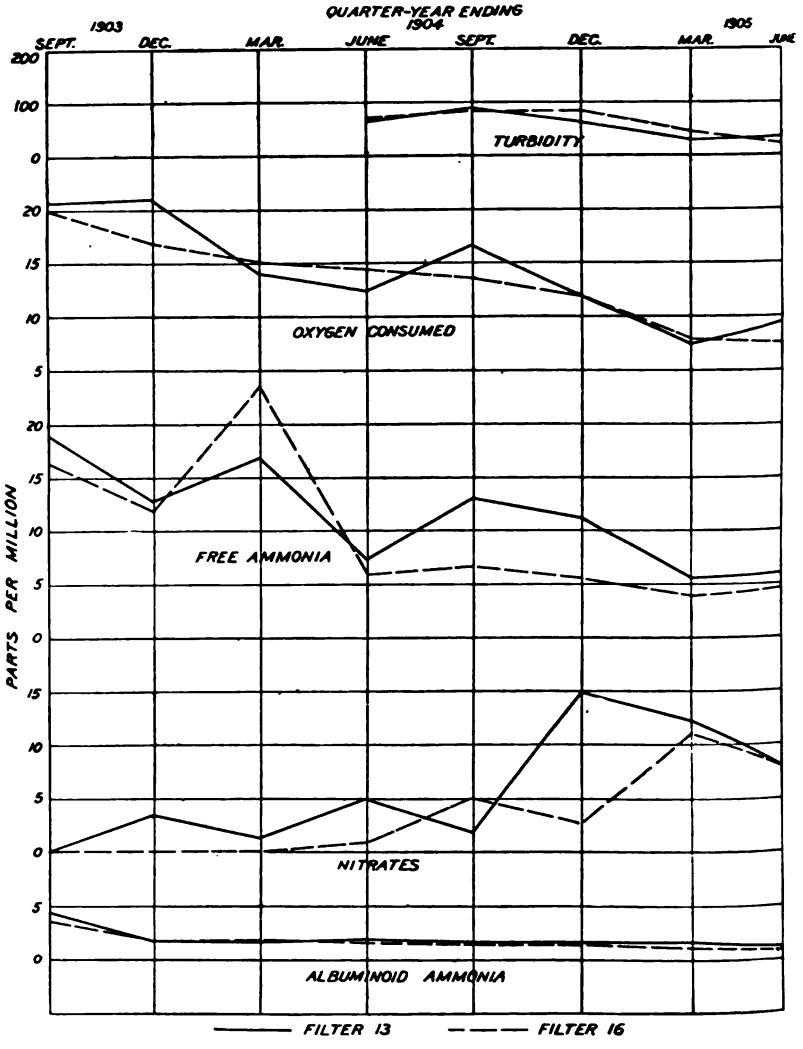


FIG. 20.—Comparison of effluents from primary-contact beds at different rates.

fillings, later, three fillings a day. Tank No. 19 received septic effluent from tank No. 10, which had been subjected to twenty-four hours of septic action and six hours' additional storage in a small dosing tank, into which the effluent from No. 10 flowed continuously. The analyses of the effluents from Nos. 19 and 20, as well as from their secondary

eds, Nos. 17 and 18, are shown in fig. 21. It will be noticed that the fluent of tank No. 20 was markedly superior to that of No. 19 in very respect, except, for part of the time, in its albuminoid-ammonia ontent. The effluent from No. 20 was often nonputrescible, while iat from No. 19 was always foul and offensive. As pointed out bove, the septic treatment was efficient in preventing clogging, the nal capacities of tanks Nos. 19 and 20 being 38 and 26 per cent, spectively. This advantage is, however, dearly bought, since the ptic effluents from Boston sewage evidently contain substances imical to bacterial action, which seriously interfere with subsequent irification. The possibilities of preliminary septic treatment before ontact filtration can not be considered as exhausted, since only this ng period (twenty-four hours' storage in the septic tank and six ours in the dosing tank) has been tried; a shorter period might move solids without interfering so seriously with the contact bed. urthermore, the harmful effect of the septic treatment might be rgely minimized by special aeration before final treatment. All iat the experiments have so far shown is that thirty hours of septic eatment yields unsatisfactory results, while crude sewage may be eated with the production of a good effluent at the risk of clogging, hich would necessitate the renewal of the beds at intervals of some ears. It is probable that a shorter septic period approaching more early the condition of plain sedimentation would maintain the apacity of the beds without corresponding harmful effects. The nalyses of the effluents from the secondary filters, tanks Nos. 17 and 8, are also plotted in fig. 21. In nitrogenous constituents and in vailable oxygen the effluent of tank No. 18 was much better than hat of No. 17. The former was clear and stable, the latter generally lark-colored and smelling of hydrogen sulphide and often failing to ass the incubator test.

The general results of these experiments on contact treatment, as neasured by oxygen consumed, are plotted in fig. 22. Like fig. 7 p. 68), for experiments at other places, it shows that a single contact vill remove from one-third to one-half of the organic constituents of ewage, with the production of an improved but still putrescible ffluent. Tanks Nos. 13 and 16, of one-half inch stone, form an exeption, since their effluents were fairly stable toward the end of he experiments. This efficiency, as has been explained (pp. 133–134), vas obtained at the expense of serious surface clogging. The double-ontact treatment effected a removal of one-third to one-half of the emaining organic matter, producing a satisfactory effluent in the case f the treatment of crude sewage.

To summarize the conclusions arrived at in regard to the construcion of contact beds, it appears that a 4-foot depth gives somewhat

better results than a 6-foot depth, but with greater capacity loss and lower rates. Either coke, brick, or broken stone, or probably any other hard material, may be used for filling, with a slight advantage

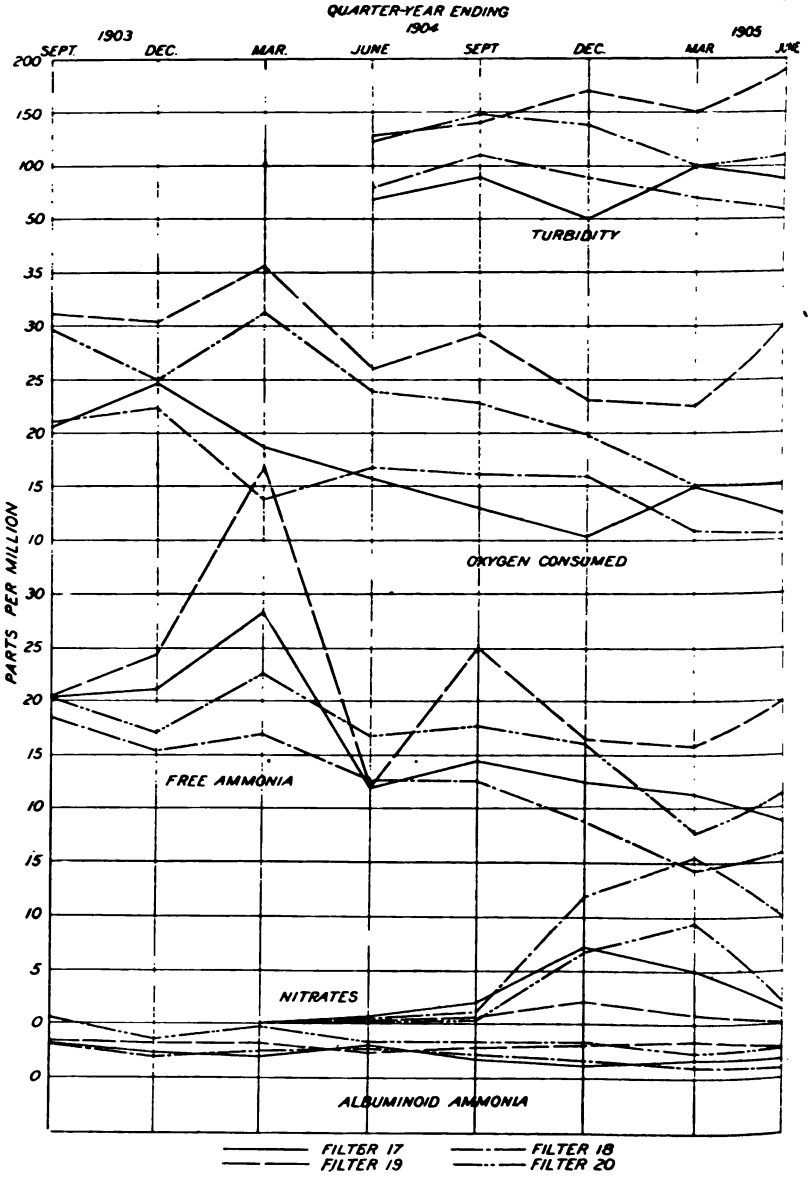


FIG. 21.—Comparison of effluents from double-contact systems taking crude and septic sewage.

for coke. The size of the material is more important than the kind. Half-inch stone gives much better results than coarser material, yielding a nonputrescible effluent even with a single contact. The

ırface of such beds must be cleaned once a year or oftener. With ½-inch stone the surface deposits need not be removed so frequently, nd with still coarser material, such as 2-inch coke, the surface needs ractically no attention; but all effluents from beds of material over ne-half inch in diameter require treatment in secondary beds. In very case the beds treating crude sewage will lose capacity so rapidly s to necessitate renewal.

The contact beds have been operated most satisfactorily with three llings a day, giving a single-contact rate for 6-foot beds of 1.2 with ne-stone filling, 1.4 with coarse stone, 1.8 with 2-inch coke, and with brick. The brick bed might be built, according to Dibdin's riginal plan (Dibdin, 1904), of slate, so as to gain a still larger apacity. With any material other than the one-half inch stone a econd contact would be necessary, reducing the rate on the double ystem, as a whole, to between 0.6 and 1.

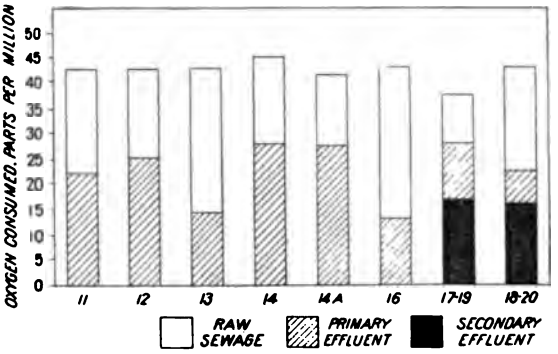


FIG. 22.—Comparison of sewages and effluents from single and double contact beds.

CONCLUSIONS BEARING ON THE TREATMENT OF BOSTON SEWAGE.

Nothing has so far been said about the process of purification by ickling over beds of coarse material. According to the results of ecent English experiments this should be the most promising method f all. Three of the tanks have been operated on this principle—No. 5 for the whole two years and Nos. 22 and 23 during 1904–5. They ere operated at high rates—from 1.5 to 2.5 million gallons per acre er day—and produced somewhat turbid effluents which after sedimentation were nonputrefactive. They were entirely free from surace clogging. It does not seem justifiable however to lay stress on he results obtained. The two most important points in the operaion of the trickling filter are the distribution system and the effect of veather conditions. While sand filters and contact beds may fairly e tested in experiments like those recorded in this paper, it is apparnt that trickling filters of only 16 square feet area, dosed with tipping uckets and operated under cover, do not furnish a criterion of actu

conditions. It has therefore been decided to conduct during 1906 a series of experiments on a larger scale, out of doors, and to postpone any discussion of trickling-filter results until those experiments are completed. The conclusions in this paper will, therefore, be limited to the discussion of the septic, sand, and contact processes.

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 1,600 pounds per million gallons of sewage and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected if desired by treatment in the septic tank. An open tank operates as well as a closed tank, and there is no marked advantage in filling the tank with stone. Varying the storage period from twelve to forty-eight hours produces no difference in the effluents which is measurable by analytical results. All the tanks removed nearly two-thirds of the suspended matter and yielded an effluent which was clear but much darkened by hydrogen sulphide. The tanks on an average received 50 pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which 30 pounds were discharged in the effluent, 15 to 17 pounds decomposed and 3 to 5 pounds stored as sludge. In the decomposition of sludge the length of the septic period is of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed, is twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments crude Boston sewage has been successfully filtered through a 2-foot bed of sand with an effective size of 0.14 millimeter, at a rate of 0.4 million gallons per acre per day, divided into four doses in the 24 hours. Such high rates should not be expected in actual practice, but it is believed that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds were clear, bright, and well purified. The depth of the beds can not safely be reduced below 2 feet. Preliminary septic treatment for twelve or twenty-four hours does not improve the effluents obtained with sand filtration, although it makes the care of the surface of the beds somewhat easier.

Crude Boston sewage may be treated in single-contact beds of fine stone (one-half inch in diameter) at a rate of about 1.2 million gallons per acre per day. The effluent is only partially purified, but is generally so stable as to be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clog rapidly and the surface needs much attention. The double-contact

ı of treatment, in primary beds of 2-inch material and sec- ' beds of one-half-inch material, yields a fairly well purified able effluent at a rate on the combined double system of about llion gallons per acre per day with beds 6 feet deep. Such a ı clogs much less seriously, but nevertheless loses sufficient ty to require renewal every few years. Preliminary septic ıent obviates this capacity loss to a considerable extent. In experiments a thirty-hour septic period produced an effluent without aeration was so difficult to purify as to interfere seri- with the efficiency of the contact beds. There is little doubt his difficulty could be overcome by aeration or by shortening ptic period. The most practical of the methods which have ıtudied would appear to be the treatment of sewage, either 'nted or subjected to a very short period of septic action, in -contact beds. The process of trickling filtration remains to ısidered in a further report, but incomplete results obtained present time indicate that this method will probably prove ɔr to any so far tested.

ACKNOWLEDGMENTS.

writers desire to express their acknowledgments to Mr. E. S. of the Boston sewer department, for many courtesies; to . W. S. Johnson and Leonard Metcalf for advice in regard to ı points in the conduct of the experiments; to Prof. L. P. ;utt and Mr. G. W. Fuller for suggestions concerning the pres- ɔn of results; and to Messrs. G. R. Spalding, W. H. Beers, /. T. Carpenter for assistance in analytical work and in the ation of tables and diagrams.

BIBLIOGRAPHY.

. J. W., 1902. Sewage-purification plants: Journal of the Western Society of ;ineers, vol. 7, p. 113.

ıN PUBLIC HEALTH ASSOCIATION, 1905. Report of committee on standard meth- of water analysis: Journal of Infectious Diseases, Supplement, No. 1, p. 1.

DENTON, J., 1882. Sewage disposal, ten years' experience, with notes on sewage ning. London.

M. N., 1904. British sewage works. New York.

R, F. A., 1904. The use of the septic tank in connection with sewage-disposal ks: Journal of the Association of Engineering Societies, vol. 32, p. 251.

R, F. A., 1905. The sewage-disposal works at Saratoga, N. Y.: Journal of the ociation of Engineering Societies, vol. 34, p. 33.

E, S., 1904. The purification of sewage. London.

Y, 1897. Ueber die organische Ernährung grüner Pflanzen und ihre Bedeutung ler Natur: Biologisches Centralblatt, vol. 17, p. 1.

, 1898. Annual report of the Street Department for the year 1897.

. 1904. *Annual report* of the Street Department for the year 1903.

BOULLANGER, E., and MASSOL, L., 1903. Études sur les microbes nitrificateurs: Annales de l'Institut Pasteur, vol. 17, p. 492.

BREDTSCHNEIDER, A., 1905. Die Reinigung des städtischen Abwassers im Brockenkörper ist rein mechanische: Gesundheits-Ingenieur, vol. 28, p. 254.

BREDTSCHNEIDER, A., and THUMM, K., 1904. Die Abwasserreinigung in England: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 3, p. 1.

BROCKTON, 1898–1905. Annual reports of the city engineers and the sewage commissioners of the city of Brockton for the years 1897 to 1904.

BRUCH, W., 1899. Das biologische Verfahren zur Reinigung von Abwässern. Berlin.

CALMETTE, A., 1901. Les procédés biologiques d'épuration des eaux résiduaires: Revue d'Hygiène, vol. 23, p. 2.

CLARK, H. W., 1896–1905. Experiments upon the purification of sewage and water at the Lawrence experiment station: Annual reports of the Massachusetts State board of health for the years 1895 to 1904. Boston.

CLARK, H. W., 1902. A study of the stability of the effluents of sewage filters of coarse materials, including investigations upon putrefaction and secondary decomposition: Annual report of the Massachusetts State Board of Health for the year 1901. Boston.

CLARK, H. W., and GAGE, S. D., 1905. The functions of various types of bacteria in the purification of sewage, with some methods for their quantitative determination: Engineering News, vol. 53, p. 27.

CLOWES, F., and HOUSTON, A. C., 1904. The experimental bacterial treatment of London sewage. London.

CONNECTICUT, 1899. Report of the Sewage Commission to the General Assembly of the State of Connecticut, January session of 1899. Hartford.

CONNECTICUT, 1903. Fourth Annual Report of the Sewage Commission to the Governor for the year 1902. New Haven.

DIBDIN, W. J., 1903. The purification of sewage and water. 3d ed. London and New York.

DIBDIN, W. J., 1904. Recent improvements in methods for the bacterial treatment of sewage. London.

DU MARÈS, J. B., 1883. Le sewage; son utilisation et son épuration. Bruxelles et Paris.

DUNBAR, Dr., 1905. Ist die Wirkung der Oxydationskörper eine rein mechanische? Gesundheits-Ingenieur, vol. 28, p. 249.

DUNBAR, Prof., and THUMM, K., 1902. Beitrag zum derzeitigen Stande der Abwässerreinigungsfrage, mit besonderer Berucksichtigung der biologischen Reinigungsverfahren. Berlin.

FARNSTEINER, K., 1902. Leitfaden für die chemische Untersuchung von Abwässer. Berlin.

FROST, W. D., 1904. The antagonism exhibited by certain saprophytic bacteria against the *Bacillus typhosus* Gaffky: Journal of Infectious Diseases, vol. 1, p. 599.

FULLER, G. W., 1903. The composition of sewage in relation to problems of disposal: Technology Quarterly, vol. 16, p. 132.

FULLER, G. W., 1905 a. Sewage disposal in America: Transactions American Society of Civil Engineers, vol. 54, p. 147.

FULLER, G. W., 1905 b. Concerning sewage disposal from the standpoint of poilution of oysters and other shellfish, and especially with reference to their transmission of typhoid fever: Journal of Franklin Institute, vol. 160, p. 81.

GOODNOUGH, X. H., 1903. Report of the committee on Charles River dam, p. 293. Boston.

GRIGGS, J., 1905. Paper read before Central States Waterworks Association at Columbus, Ohio, September 12. Abstract in Engineering News, vol. 54, p. 313.

GRÜNBAUM, A. S., 1902. Notes on experiments on sewage disposal in Germany. Thompson Yates Laboratories Report, vol. 3, pt. 1, p. 109. London, New York, and Bombay.

HANLEY, 1904. Report of Dr. George Reid, county medical officer for Staffordshire, presented to the sanitary committee July 2.

HARRISON, W. H., 1900. The bacteriological treatment of sewage: Journal of the Society of Chemical Industry, vol. 19, p. 511.

HAZEN, A., 1890. Report of experiments upon the chemical precipitation of sewage at the Lawrence experiment station in 1889. Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 2, p. 737.

HAZEN, A., 1894. Chemical precipitation of sewage at the World's Columbian Exposition, Chicago, 1893: Annual report of the Massachusetts State Board of Health for the year 1893. Boston.

HAZEN, A., 1904. On sedimentation: Transactions American Society of Civil Engineers, vol. 53, p. 45.

HERING, R., 1888. Notes on the pollution of streams: American Public Health Association, vol. 13, p. 272.

HILL, A. B., 1897. Filtration of sewage through coal: Journal of the Sanitary Institute, vol. 18, p. 554.

HOPPE-SEYLER, 1886. Ueber die Gärung der Cellulose unter Bildung von Kohlensäure und Methan: Zeitschrift für physiologische Chemie, vol. 10, p. 201.

JACKSON, D. D., 1900. Permanent standards for use in the analysis of water: Technology Quarterly, vol. 13, p. 314.

JACKSON, D. D., and WHIPPLE, G. C., 1901. Method of calibrating turbidimeters: Technology Quarterly, vol. 14, p. 285.

JOHNSON, G. A., 1905. Sewage disposal: Ohio Sanitary Bulletin, January-March.

JORDAN, E. O., RUSSELL, H. L., and ZEIT, F. R., 1904. The longevity of the typhoid bacillus in water: Journal of Infectious Diseases, vol. 1, p. 641.

KINNICUTT, L. P., 1898. Recent work in England on the purification of sewage: Journal of the American Chemical Society, vol. 20, p. 185.

KINNICUTT, L. P., 1902. The present status of the sewage problem in England: Journal of the Association of Engineering Societies, vol. 28, p. 323.

KINNICUTT, L. P., 1905. The intermittent filtration of sewage as practiced in America: Journal of Preventive Medicine, vol. 13, p. 633.

KINNICUTT, L. P., and EDDY, H. P., 1902. The action of the septic tank on acid iron sewage: Third Annual Report Connecticut Sewerage Commission. Hartford.

LEEDS, 1900. Report on sewage disposal.

LEEDS, 1905. Report on the experiments in sewage disposal carried out at the Knostrop sewage works, Leeds, from 1898 to 1905. By Col. T. W. Harding and W. H. Harrison.

LEICESTER, 1900. Report to the highway and sewage works and farms committees, by E. G. Hawley.

LOWCOCK, S. R., 1893. Experiments on the filtration of sewage: Proceedings of the Institute of Civil Engineers, vol. 115, p. 297.

MANCHESTER, 1900 a. Expert report on treatment of Manchester sewage. Dated October 30, 1899.

MANCHESTER, 1900 b. Annual Report of the Rivers Department for the year ending March 28, 1900.

MANCHESTER, 1901. Annual Report of the Rivers Department for the year ending March 27, 1901.

MANCHESTER, 1902. Annual Report of the Rivers Department for the year ending March 26, 1902.

MANCHESTER, 1903. Annual Report of the Rivers Department for the year ending March 25, 1903.

MANCHESTER, 1904. Annual Report of the Rivers Department for the year ending March 30, 1904.

MARTIN, A. J., 1905. The sewage problem. London and New York.

MASSACHUSETTS, 1896–1905. Annual reports of the State Board of Health for 1895 to 1904.

METCALF, L., 1901. The antecedents of the septic tank: Transactions American Society of Civil Engineers, vol. 46, p. 456.

MILLS, H. F., 1890. Filtration of sewage and of water: Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 2, p. 1.

NOLL, H., 1901. Bestimmung der Saltpetersäure aus colorimetrischem Wege: Zeitschrift für angewandte Chemie, vol. 14, p. 1317.

OLDHAM, 1901. The treatment of sewage. 1900.

PAWTUCKET, 1901. Annual Report of the Board of Public Works, year ending September 30, 1901.

PAWTUCKET, 1904. Annual Report of the Board of Public Works, year ending September 30, 1904.

PHELPS, E. B., 1904. A critical study of the methods in current use for the determination of free and albuminoid ammonia in sewage: Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 87.

PHELPS, E. B., 1905 a. The interpretation of a sewage analysis: Technology Quarterly, vol. 18, p. 40.

PHELPS, E. B., 1905 b. The determination of the organic nitrogen in sewage by the Kjeldahl process: Journal of Infectious Diseases, Supplement No. 1, p. 255; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 101.

PHELPS, E. B., and FARRELL, F. W., 1905. Mode of action of the contact filter in sewage purification: Journal of Infectious Diseases, Supplement No. 1, p. 229; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 61.

PRATT, R. W., jr., 1904. Report of an examination of sewage-purification plants in Ohio: Eighteenth Annual Report Ohio State Board of Health. Springfield, Ohio.

PRATT, R. W., jr., 1905. Sewage purification, with special reference to the problem in Ohio: Journal of the Association of Engineering Societies, vol. 34, p. 310.

RAFTER, G. W., 1897. Sewage irrigation: Water-Supply and Irrigation Paper No. 3, United States Geological Survey. Washington.

RAFTER, G. W., and BAKER, M. N., 1894. Sewage disposal in the United States. New York and London.

RICHARDS, E. H., and JORDAN, E. O., 1890. Investigations upon nitrification and the nitrifying organisms: Special Report of the State Board of Health of Massachusetts on Water Supply and Sewerage, pt. 2, p. 865.

RICHARDS, E. H., and WOODMAN, A. G., 1904. Air, water, and food. 2d ed. New York.

RIDEAL, S., 1901. Sewage and the bacterial purification of sewage. London and New York.

RIVERS POLLUTION COMMISSION, 1870. First report of the commission appointed in 1868 to inquire into the best means of preventing the pollution of rivers. London.

ROBINSON, H., 1896. Sewerage and sewage disposal. London and New York.

ROECHLING, H. A., 1892. Sewage farms at Berlin: Minutes of Proceedings of the Institution of Civil Engineers, vol. 109, p. 179.

ROYAL SEWAGE COMMISSION, 1901. Interim Report of the Royal Commission on Sewage Disposal. London.

ROYAL SEWAGE COMMISSION, 1902 a. Second Interim Report of the Royal Commission on Sewage Disposal.

ROYAL SEWAGE COMMISSION, 1903. Third Interim Report of the Royal Commission on Sewage Disposal.

ROYAL SEWAGE COMMISSION, 1904 a. Pollution of tidal waters, with special reference to the contamination of shellfish: Fourth Interim Report of the Royal Commission on *Sewage Disposal*, vol. 2.

ROYAL SEWAGE COMMISSION, 1904 b. Chemical report by Dr. G. McGowan: Fourth Interim Report of the Royal Commission on Sewage Disposal, vol. 4, pt. 2.

ROYAL SEWAGE COMMISSION, 1904 c. General report: Fourth Interim Report of the Royal Commission on Sewage Disposal, vol. 4, pt. 1.

SCHLOESING, T., and MUNTZ, A., 1877. Sur la nitrification par les ferments organisés: Comptes Rendus, vol. 84, p. 301.

SCHULTZ-SCHULTZENSTEIN, 1903. Ueber die nitrificierenden Mikro-organismen der Filterkörper biologischer Abwässer-Reinigungsanlagen: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 2, p. 1; translated by A. E. Kimberly, Technology Quarterly, vol. 17, 1904, p. 186.

SCHURY, 1905. Die biologische Versuchsklāranlage der Stadt Stuttgart auf der Prag: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 5, p. 1. Berlin.

SCOTT-MONCRIEFF, W. D., 1899. High nitrification in sewage treatment. Journal of the Sanitary Institute, vol. 20, p. 653.

SMITH, J., 1901. The sewerage and sewage disposal of Burton-upon-Trent. Proceedings of the Institution of Civil Engineers, vol. 146, p. 262. London.

STEARNS, F. P., 1890. The pollution and self-purification of streams: Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 1, p. 785.

STEURNAGEL, 1904. Die Probekläranlage zu Cöln-Niehl und die daselbst angestellten Untersuchungen und erzielten Ergebnisse: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 4, p. 1. Berlin.

STODDART, F. W., 1893. Water analysis—the interpretation of results: The Practitioner, vol. 51, p. 378.

STODDART, F. W., 1905. The tanking of sewage: Journal of Preventive Medicine, vol. 13, p. 571.

STUDICHUM, G., 1903. Bacterial treatment of sewage. London.

STUMM, K., 1902. Beitrag zur Kentnisse des sog. biologischen Verfahrens, insbesondere die bei der Herstellung und dem Betriebe biologischer Abwässerreinigungsanlagen zu beachtenden allgemeinen Gesichtspuncte: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung zu Berlin, vol. 1, p. 86.

STUMM, K., and PRITZKOW, A., 1903. Versuche über die Reinigung der Abwässer von Tempelhof bei Berlin durch das biologische Verfahren: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 2, p. 127.

UNITED STATES GEOLOGICAL SURVEY, 1900. Operations at river stations, 1899, pt. 1: Water-Supply and Irrigation Paper No. 35. Washington.

UNITED STATES GEOLOGICAL SURVEY, 1901. Operations at river stations, 1900, pt. 1: Water-Supply and Irrigation Paper No. 47. Washington.

UNITED STATES DEPARTMENT OF STATE, 1895. Consular Reports, vol. 48, No. 173.

VARING, G. E., jr., 1895. The purification of sewage by forced aeration. Newport, R. I.

VARINGTON, R., 1882. Some practical aspects of recent investigations in nitrification: Journal of the Society of Arts, vol. 30, p. 532.

VATSON, J. D., 1903. The purification of sewage. Birmingham.

VESTON, R. S., 1905. Notes on the determination of nitrogen as nitrates in waters: Journal of the American Chemical Society, vol. 27, p. 281.

VILCOX, J. E., and REID, G., 1904. The importance of uniform distribution of sewage on filters: Journal of the Royal Sanitary Institute, vol. 25, p. 494.

VINSLOW, C.-E. A., 1905 a. The number of bacteria in sewage and sewage effluents determined by plating upon different media and by a new method of microscopical enumeration: Journal of Infectious Diseases, Supplement No. 1, p. 209; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 41.

WINSLOW, C.-E. A., 1905 b. A winter visit to some sewage-disposal plants in O consin, and Illinois: Journal of the Association of Engineering Societies, vol. 3

WINSLOW, C.-E. A., and PHELPS, E. B., 1905. The chemical and bacterial comp the sewage discharged into Boston Harbor from the south metropolitan distri nal of Infectious Diseases, Supplement No. 1, p. 175; Contributions from the Research Laboratory and Sewage Experiment Station, vol. 1, p. 7.

WINSLOW, C.-E. A., and WILLCOMB, G. C., 1905. Tests of a method for the dire scopic enumeratioh of bacteria: Journal of Infectious Diseases, Supplement 273; Contributions from the Sanitary Research Laboratory and Sewage Ex Station, vol. 1, p. 119.

WOODMAN, A. G., WINSLOW, C.-E. A., and HANSEN, P., 1902. A study of self-pu in the Sudbury River: Technology Quarterly, vol. 15, p. 105.

WORCESTER, 1905. Annual Report of the Superintendent of Sewers of the city of V for the year ending November 30, 1904.

YORK, 1901. Report of the city surveyor on sewage-purification experiments.

ZAHN, C., 1903. Weitere versuche über die Reinigung des Charlottenburger Abwä Pumpstation Westend durch das biologische Verfahren: Mitteilungen aus de lichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berli p. 164.

INDEX.

A. Page.

ccrington, England, septic treatment at... 49, 50, 51, 118
trickling filtration at..... 80, 83, 84, 88
cheres, France, sewage farm at. *See* Paris.
cid-iron waste, effect of, on sewage..... 12, 41, 50
cton, England, septic treatment at..... 51
deney process of sewage treatment, use of, in Ireland..... 35
eration, forced, experiments on..... 75–76
erobic oxidation. *See* Contact beds; Filtration; Sewage farming.
lbumen, oxidation of..... 16
lbuminoid ammonia, method of expressing values for..... 17
ldershot, England, sewage farm at..... 27
lgæ, influence of, in oxidation..... 17
lliance, Ohio, chemical precipitation at... 96
ltrincham, England, sewage farm at..... 27
lvord, J. W., on septic process..... 46, 48
Ammonia, method of expressing values for. 17
Anaerobic putrefaction. *See* Septic tank.
Analyses, description of, at sewage experiment station..... 107–111
of chemical effluents..... 31, 33, 41, 56, 80, 117
of contact effluents..... 56, 57, 58, 61, 66, 68, 70, 71, 86, 88, 136–139, 143, 144, 146, 147
of effluents from sewage farms..... 27, 90
of effluents from strainers..... 117
of sand-filter effluents..... 39, 40, 41, 58, 129
of sedimentation-tank effluents..... 90, 117
of septic effluents..... 40, 45, 47, 48, 57, 58, 68, 70, 71, 77, 82, 83, 88, 90, 117, 122–123
of septic-tank contents..... 124
of sewage..... 27, 31, 33, 39, 40, 41, 45, 47, 48, 57, 58, 61, 68, 70, 71, 77, 80, 81, 82, 83, 88, 90, 114, 117, 123, 147
of trickling-filter effluents..... 77, 78, 80, 81, 82, 83, 84, 85–86, 88
of water from Illinois and Michigan Canal..... 17
Analytical methods. *See* Methods, analytical.
Andover, Mass., intermittent filtration at.. 40
septic treatment at..... 52
Ashtead, England, experiment with sewage tank at..... 43, 45
trickling filtration at..... 78
Aylesbury, England, contact treatment at..... 68, 69, 70
treatment in coarse filters at..... 118

B.

Bacteria, disposal of, in sewage purification. 12, 37
presence of, in sewage..... 11, 37
rôle of, in sewage purification..... 13, 17, 35, 37, 38, 44, 54, 72, 73

Page.

Bailey-Denton, J., experiments by, on sewage filtration..... 36
Baker, M. N., on anaerobic filters..... 45
on chemical precipitation..... 31
on contact process..... 61, 89
on English purification processes..... 91
on septic process..... 46, 50, 51
on sewage farming..... 28
on trickling filtration..... 80, 88
See also Rafter, G. W., and Baker, M. N.
Barbour, F. A., on septic process..... 50, 51, 53, 121
on septic treatment of sludge..... 48
Barking, England, chemical precipitation at..... 30–31
contact treatment at. 54, 55, 56, 57, 63, 66, 67, 73
dissolved oxygen in Thames River at... 19
Barrhead, England, contact treatment at.. 73
septic treatment at..... 51
Barwise, S., on contact process..... 59, 67
on septic process..... 49
on sewage farming..... 26
on sewage nitrification..... 38
on trickling filtration..... 79, 80, 82, 83, 84, 86
Battersea, England, dissolved oxygen in Thames River at..... 19
Beaumont-Leys sewage farm. *See* Leicester, England.
Beddington, England, sewage farm at..... 27
Beers, W. H., acknowledgments to..... 149
work of..... 9
Belfast, Ireland, trickling filtration at..... 87
Bell, ——, on trickling filtration..... 80–81
Berlin, contact treatment at..... 59, 65, 74
first sewerage in..... 11
royal testing station at, investigations of, on purification processes.... 93–94
sewage farms at..... 25
trickling filtration at..... 94
See also Grosslichterfelde.
Birmingham, England, chemical precipitation at..... 31, 90
contact treatment at..... 58, 66, 67, 74
septic treatment at..... 46, 48, 49, 50, 52, 90, 118
sewage farming at..... 26, 90
trickling filtration at..... 79–80, 83, 91
Blackburn, England, contact treatment at..... 67, 68, 69, 70
treatment in coarse filters at..... 118
Blackstone River, pollution of, by sewage of Worcester, Mass..... 32–33
Blackwall, England, dissolved oxygen in Thames River at..... 19
Bokorny, ——, on oxidation..... 17
Boullanger, E., and Massol, L., on work of bacteria in sewage purification. 38
Bredtschneider, A., on contact process..... 7

Page.
Bredtschneider, A., and Thumm, K., investigations by, on purification processes 94
on contact process 58, 71
on sewage farming 26
on trickling filtration 78, 80, 81, 83
Bridgeport, Ill., analysis of water of Illinois and Michigan Canal at 17
Brockton, Mass., intermittent filtration at 40, 41, 131
septic treatment at 48
sewage of, strength of 111
sludge from filtration process at 42
Bruch, W., on purification processes.. 65, 66, 74, 93
Brunswick, Germany, sewage farming at... 26
Bunker, G. C., work of 9
Bunzlau, Prussia, sewage farming at 24
Burnley, England, contact treatment at. 63, 67, 73
septic treatment at 49, 51, 118
Burton, England, trickling filtration at 84
Buxton, England, trickling filtration at 82, 84

C.

Calmette, A., on purification processes 94
Cambridge, England, sewage farm at 27
Cameron, Donald, development of anaerobic process by 43–44
Campbell, J. L., experiments by, on purification processes 91
Candy, — —, on trickling filtration 82
Candy-Whittaker trickling filter, construction of 80
Canton, Ohio, chemical precipitation at 96
Carlisle, England, contact treatment at 67
Carpenter, W. T., acknowledgments to 149
work of 9
Caterham, England, septic treatment at... 52
trickling filtration at 78
Cellulose, oxidation of 16
Chadwick, ———, and Murchison, ———, theory of, concerning origin of infectious disease 10
Champaign, Ill., sewage tank at 43
Chapel-Izod, Ireland, chemical precipitation at 35
Charlottenburg, Germany, contact treatment at 58, 94
Cheltenham, England, sewage farming at.. 26
Chemical precipitation, cost of 31, 34
defects of 32
disposal of sludge from 32
effluents of, analyses of. *See* Analyses.
English patents for 29, 31
rates of 30, 32, 34
treatment of sewage by 29–35, 41, 89, 90, 91, 92, 93, 94, 96, 117, 118
Chesbrough, E. S., sewerage system designed by, for Chicago 10–11
Cheshire, England, sewage farm at 27
Chesterfield, England, trickling filtration at. 80, 84
Cheyenne, Wyo., sewage farm at 28, 96
Chicago, first sewerage in 10–11
Chondrin, oxidation of 16
Chorley, England, chemical precipitation at. 118

Page
Clark, H. W., on contact process 72, 73
on intermittent filtration 131, 132
on septic process 44, 50, 52
on trickling filtration 85
on variations in strength of sewage 107
Clark, H. W., and Gage, S. D., on bacteria in septic treatment 48
Climate, effect of, on purification processes 22, 28–29, 41–42, 86, 96, 129–132
Clinton, Mass., intermittent filtration at... 40, 42
Cloaca Maxima, function of 9
Clowes, F., and Houston, A. C., experiments by, on contact process 56
on contact process 55, 56, 57, 59, 63, 65, 66, 67
on purification processes at London 89
Columbus, Ohio, experiments at, on purification processes 95–96
trickling filtration at 86
Concord, Mass., intermittent filtration at.. 40, 42
Connecticut, intermittent filtration in 96
Connecticut sewage commission, on dissolved gases in Thames River, England 19
Contact bed, multiple-surface. *See* Multiple-surface bed.
Contact beds, capacity of. 59, 65, 92, 135–136, 140, 142
effluents from, analyses of. *See* Analyses.
rates of treatment in 55, 56, 57, 58, 67, 68–69, 70, 71, 73, 133, 134, 139, 142, 147, 148, 149
treatment of sewage in 53–75, 88, 89, 91, 92, 93, 94, 95, 96, 132–147, 148–149
Copeland, W. E., experiments by, on purification processes 95–96
Corbett, ———, experiments by, on trickling filters 77, 78
on trickling filtration 82
Craigentinny, Scotland, sewage farm at. *See* Edinburgh.
Creer, A., investigations by, on purification processes 91
Crops, growing of, on filter beds 41
healthfulness of, grown on sewage farms. 28
See also Sewage farming.
Crossness, England, chemical precipitation at 30–31
contact treatment at 56, 57, 66
dissolved oxygen in Thames River at... 19
septic treatment at 49
Croydon, England, contact treatment at... 67
sewage farm at 27

D.

Danzig, Prussia, sewage farm at 24–25, 26
Deer Island Light, Boston Harbor, sewage discharged near, amount of 20
Degener process of sewage treatment, use of, in Germany 34–35
Derbyshire, England, trickling filtration in. 80
Detritus, removal of 114–116
See also Screening; Sedimentation.
Dibdin, W. J., experiments by, on contact process 54–56, 66
investigations by, on chemical precipitation 29–30

Page

Dibdin, W. J., on anaerobic putrefaction... 52
on chemical precipitation..... 31
on contact process..... 57, 59, 72
on multiple-surface bed..... 59, 141, 147
on necessity of anaerobic putrefaction.. 53
on oxidation..... 16, 76
on rôle of bacteria in sewage purification. 54
on self-purification of Thames River, England..... 18
on septic process..... 50, 74
on trickling filtration..... 77, 81, 90
Dilution, disposal of sewage by..... 16-23, 26, 90, 92, 93, 94, 96
Disinfection processes of sewage treatment, defects of..... 35
Dorr, E. S., acknowledgments to..... 149
Double-contact process. *See* Contact beds.
Drift, Glacial, use of, in construction of filters..... 41
Dronfield, England, trickling filtration at.. 84
Drown, T. M., work of, on sewage-purification investigations..... 37
Ducat, ———, experiments by, on trickling filters..... 77, 80
on trickling filtration..... 81, 82, 83
Ducat trickling filter, construction of..... 79
Du Marès, J. B., on sewage farming..... 24
Dunbar, ———, experiments by, on contact process..... 93
on contact process..... 72
Dunbar, ———, and Thumm, K., on contact process..... 61, 62, 65, 66, 68, 72, 73, 74, 75, 93, 140
on work of filters..... 108
Dundrum, Ireland, chemical precipitation at..... 35
Dupré, ———, on rôle of bacteria in sewage purification..... 54

E.

East Cleveland, Ohio, septic treatment at.. 46, 76
Eastry, England, contact treatment at.... 71
Eddy, H. P. *See* Kinnicutt, L. P., and Eddy, H. P.
Edinburgh, Scotland, sewage farming at... 24, 26
Effluents, analyses of. *See* Analyses.
septic composition of, figure showing... 120
England, chemical precipitation in..... 29-32, 89, 90, 91, 92, 93
contact treatment in.... 54-57, 58, 59, 61-64, 65, 66, 67-68, 69, 70, 71, 73-74, 88, 89, 91, 92
intermittent filtration in..... 36
septic treatment in..... 43-44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 88, 89, 90, 91, 92
sewage in, amount of..... 11
composition of..... 15-16
sewage-disposal practice in, recent tendencies in..... 88-93
sewage farming in . 24, 25, 26-27, 28, 90, 91, 92, 93
trickling filtration in.. 75, 77-84, 87, 89-90, 91, 92
See also Great Britain; London; *names of towns.*

Page.

Erith, England, dissolved gases in Thames River at..... 19
Exeter, England, contact treatment at..... 63, 65-66, 67
septic treatment at..... 43, 48, 49, 50, 88-89

F.

Falkenberg, Germany, sewage farm at. *See* Berlin.
Farming, sewage. *See* Sewage farming.
Farrell, F. W., work of..... 9
See also Phelps, E. B., and Farrell, F. W.
Fat, oxidation of..... 16
Filter, contact. *See* Contact beds.
intermittent. *See* Filtration, intermittent.
intermittent continuous. *See* Filtration, trickling.
ladder. *See* "Ladder filters."
percolating. *See* Filtration, trickling.
sand. *See* Filtration, intermittent.
sprinkling. *See* Filtration, trickling.
trickling. *See* Filtration, trickling.
Filtration, rates of, in anaerobic filters..... 45
rates of, in contact beds. 55, 56, 58, 67, 70, 71, 73, 87, 133, 134, 139, 140, 142, 143, 148, 149
in sewage farming..... 25, 26, 27
Filtration, intermittent, cost of, at Massachusetts plants..... 42
effect on, of winter weather 41-42, 130-132
effluents from, analyses of. *See* Analyses.
impracticability of, in England..... 88
limitations of..... 53-54
rates of..... 36, 37, 38, 39, 40, 42, 52, 54, 127, 128, 130, 131, 132, 148
treatment of sewage by..... 7, 12, 35-42, 52, 94-95, 96, 126-132, 148
Filtration, trickling, effluents from, analyses of. *See* Analyses.
rates of .. 75, 77, 78, 82-83, 84, 87, 88, 90, 92, 96, 147
treatment of sewage by..... 8, 75-88, 89-90, 91, 92, 94, 95, 96, 147-148
See also Contact beds.
Fond du Lac, Wis., septic treatment at.... 95
Fowler, ———, on gas production in septic tank..... 44
Framingham, Mass., intermittent filtration at..... 39, 40, 94
sewage of, strength of..... 111
France, experiments in, on purification processes..... 94
Frankfurt am Main, Germany, sedimentation at..... 116
Frankland, Edward, experiments by, on sewage filtration..... 35-36
Frankland, Percy, experiments by, on purification processes..... 89
Free ammonia, method of expressing value for..... 17
Frost, W. D., on typhoid bacilli in water.... 11
Fuchsine, use of, in analyses..... 110

Page.
Fuller, G. W., acknowledgments to..... 149
on chemical precipitation..... 34
on contact process..... 58,70
on organic nitrogen in sewage..... 108
on sewage in Massachusetts cities..... 11
on sewerage systems and purification plants in United States..... 23,96
Fuller, ——, experiments in charge of, at Columbus, Ohio..... 95-96

G.

Gage, S. D. *See* Clark, H. W., and Gage, S. D.
Gardner, Mass., intermittent filtration at.. 39, 40,42,94
sewage of, strength of..... 111
Garfield, ——, on trickling filtration..... 82
Gelatin, oxidation of..... 16
Gennevilliers, France, sewage farm at. *See* Paris.
Germany, chemical precipitation in... 32,34,93,94
contact treatment in..... 58, 59,60-61,65,66,68,72,73,74,75,93,94
early sewerage systems in..... 11
septic treatment in..... 93,94
sewage-disposal practice in, recent tendencies in..... 93,94
sewage farming in..... 24,25,26,28,93,94
trickling filtration in..... 94
Glasgow, Scotland, chemical precipitation at..... 32
septic treatment at..... 50
Gooch crucible, use of, in analyses..... 110
Goodnough, X. H., on capacity of sewage-disposal plants..... 42
on self-purification of streams..... 21-22
Gravesend, England, dissolved oxygen in Thames River at..... 19
Great Britain, health of towns commission, investigations of..... 10
local government board, influence of, on sewage-disposal projects..... 91-92,93
metropolitan sewage commission, investigations of..... 10
on sewage disposal..... 92
on sewage farming..... 24
rivers pollution commission, investigations of..... 10
on chemical precipitation..... 29
on self-purification of streams..... 17
on sewage disposal..... 35-36,92
royal commissions of, investigating sewage disposal, etc., list of.... 10
royal sewage commission, investigations of..... 10,92-93
on chemical precipitation..... 91
on contact process..... 57, 59,63,64,66,70,74,91
on effect of sewage on shellfish..... 21,92
on London sewage..... 11
on necessity of anaerobic putrefaction..... 52-53
on sedimentation..... 91
on septic process..... 49-50
on sewage farming..... 25-27,28
on sewage nitrification..... 38
on trickling filtration. 76,77,80,81,83,85,87

Great Britain,
in
sewage of
di
on sew
Greeley, Colo.
Greenhithe, E
Th
Greenwich, E
Th
Griggs, J., on
lu
Grossbeeren,
Se
Grosslichterfe
on
Grünbaum, A
Ge

Hamburg, Ge
first sewer
Hygienic
on
Hammersmith
Th
Hampton, En
septic trea
Hanley, Engla
Hansen, P. *S*
C.-
Harding, T. W
fic
Harding, ——
Harrison, W. I
fic
on septic p
Hastings, Neb
Hazen, Allen,
by
experimen
tio
experimen
ch
on septic t
Health, board
tio
on disposal
on intermi
on season
Ri
190
See also I
sta
Health of tow
Se
Hendon, Engl
Hering, R., on
Hering, ——
Col
Hermite proc
des
Hewson, T., in
the

Page

ale, Mass., intermittent filtration at. 40
-Seyler, ——, on character of septic effluent..... 121
d, England, trickling filtration at.... 77,79
on, A. C. *See* Clowes, F., and Houston, A. C.
rsfield, England, purification processes at..... 49–50,91
England, trickling filtration at..... 83,84

I.

igh, Earl of, investigations in charge of..... 92–93
, septic treatment in..... 95
and Michigan Canal, self-purification in..... 17
tor test, description of..... 109–110
te of Technology, Massachusetts. *See* Technology, Massachusetts Institute of.
ittent filtration. *See* Filtration, intermittent.
, chemical precipitation in..... 35
on, broad. *See* Sewage farming.
district, England. *See* Mersey and Irwell district.

J.

permanent standards, use of, in analyses..... 110
turbidimeter, use of, in analyses.... 110
, G. A., experiments by, on purification processes..... 95–96
self-purification of streams..... 22
, W. S., acknowledgments to..... 149
E. O., Russell, H. L., and Zeit, F. R., on typhoid bacilli in water..... 11

K.

ngland, dissolved oxygen in Thames River at..... 19
e, Ill., septic treatment at..... 95
ley, A. E., experiments by, on purification processes..... 95–96
n, England, chemical precipitation at..... 118
olved gases in Thames River at..... 19
tt, L. P., acknowledgments to..... 149
lerman sewage-disposal practice.... 93
eptic process..... 50
rickling filters..... 79
tt, L. P., and Eddy, H. P., on septic process..... 44
p sewage works (Leeds, England), contact treatment at..... 63

L.

r filters," experiments with, at Leeds, England..... 45
rest, Ill., septic treatment at.. 46,51,53,95
h, England, trickling filtration at.. 84
. Baldwin, experiments by, on purification processes..... 89
e, Mass., chemical precipitation at. 117
act treatment at..... 53,57–58,68,69,70,75
riment station at, establishment of. 23,37

Page.

Lawrence, Mass., experiment station at, investigations at, on sewage purification..... 6,7,23,37,38–39, 44,45, 46,47, 48,49,50, 51,53,57–58, 68,69,70,75,107,117,121,126–127,131
intermittent filtration at. 37, 38–39,126–127,131
sedimentation at..... 117
septic treatment at..... 44, 45,46,47,48,49,50,51,107,117,121
sewage of, strength of..... 111
straining at..... 117
See also Merrimac River.
Leamington, England, sewage farming at.. 25
Leeds, England, chemical precipitation at.. 89
contact treatment at..... 62, 63,66,67,68,69,70,71,74,89,118
experiments with "ladder filters" at... 45
septic treatment at.. 45,46,47,48,49,50,53,118
trickling filtration at..... 79, 80,81,83,84,85,86,87,88,89–90
Leicester, England, contact treatment at... 63, 68,69,70,73
septic treatment at..... 49
sewage farm at..... 27,91
Leicester, Mass., intermittent filtration at.. 40,42
Letts, ——, experiments by, on trickling filtration..... 87
Liernur sewerage system, use of, in Holland and Belgium..... 34
Lille, France, experiments at, on purification processes..... 94
Local government board, Great Britain. *See* Great Britain.
Lockport, Ill., analysis of water in Illinois and Michigan Canal at..... 17
London, chemical precipitation at. 29–31,89,92,118
contact treatment at.... 54–56,57,67,73,74,88
regulations in, concerning discharge of waste..... 9,10
sedimentation at..... 116
septic treatment at..... 49,50
sewage of, amount of..... 11
See also Barking; Battersea; Blackwall; Crossness; Greenwich; Hammersmith; Woolwich.
London Bridge, England, dissolved oxygen in Thames River at..... 19
Long, ——, investigations by, of self-purification in Illinois and Michigan Canal..... 17
Long Eaton, England, trickling filtration at 84
Los Angeles, Cal., sewage farm at..... 28,96
Lowcock, S. R., construction of trickling filter by..... 75
Lynn, Mass., effect of sewage disposal in shallow water at..... 21

M.

McManus, J. H., and Walker, A. W., investigations by, on effects of sewage disposal in Boston Harbor.. 20
Madison, Wis., septic treatment at..... 95
trickling filtration at..... 95
Maidstone, England, contact treatment at. 64
Malchow, Germany, sewage farm at. *See* Berlin.

Page.
Malvern, England, trickling filtration at... 75
Manchester, England, chemical precipitation at..... 31, 89
contact treatment at..... 58, 61, 63, 66, 67-68, 69, 70, 71, 73, 74, 89
loss in capacity of contact beds at, diagram showing..... 64
screening at..... 114
sedimentation at..... 114, 116
septic treatment at..... 50, 53, 118
trickling filtration at..... 87
Manchester, England, rivers department, on capacity of contact beds..... 60
Mansfield, Ohio, septic treatment at..... 95
Mansfield, ——, septic treatment at..... 51
Marion, ——, septic treatment at..... 51
Marlboro, Mass., intermittent filtration at. 39, 40, 42, 94
Martin, A. J., on anaerobic putrefaction.... 51, 52
on British commissions..... 10
on contact process..... 59, 60, 65, 67
on removal of suspended solids..... 118
on septic process..... 49
on trickling filtration..... 83, 87
Massachusetts, intermittent filtration in... 94-95
metropolitan sewerage district of, map showing..... 97
purification plants in..... 23, 94
Massachusetts board of health. *See* Health, board of, Massachusetts.
Massachusetts Institute of Technology. *See* Technology, Massachusetts Institute of.
Massol, L. *See* Boullanger, E., and Massol, L.
Mawbey, E. G., investigations by, on purification processes..... 91
Meriden, Conn., intermittent filtration at.. 39
Merrimac River, experiment station on, at Lawrence, Mass. *See* Lawrence, Mass.
seasonal conditions of, at Lawrence, Mass., 1899-1900..... 22, 23
Mersey and Irwell district, England, contact treatment in..... 74
Merthyr Tydvil, Wales, experiments on sewage filtration at..... 36
Metcalf, Leonard, acknowledgments to.... 99, 149
on receptacles for excreta in Paris..... 43
Methods, analytical, discussion of..... 107-111
Metropolitan sewage commission, Great Britain. *See* Great Britain.
Milan, Italy, sewage farming at..... 24
Millbury, Mass., nuisance created at, by Worcester sewage..... 32, 33
Mills, H. F., investigations on sewage purification in charge of..... 37, 53
on composition of sewage..... 13
on intermittent filtration..... 37
Moon Island, Boston Harbor, detritus at... 116
sewage discharged at, amount of..... 20
Mouras, ——, invention of sewage tank by. 43
Mucking, The, England, dissolved oxygen in Thames River at..... 19
Mueller, Alexander, on sewage purification by micro-organisms..... 35

Page.
Multiple-surface bed, treatment of sewage in..... 59, 134, 135, 137, 139, 141-142, 147
Muntz, A. *See* Schloesing, T., and Muntz, A.
Murchison, ——. *See* Chadwick, ——, and Murchison, ——.

N.

Naburn disposal works (York, England), contact treatment at..... [illegible]
trickling filtration at..... [illegible]
Natick, Mass., intermittent filtration at.... 40, [illegible]
New York, disposal of sewage in tide water at.....
Newbury, England, contact treatment at...
Newlands, J. A., work of.....
Newport, R. I., experiments at, on forced aeration..... 75-76
Nichols, W. R., reports by, on sewage disposal..... 23
Nitrification. *See* Bacteria.
Nore, The, England, dissolved oxygen in Thames River at..... 19
Nottingham, England, sewage farm at..... 27
Nut Island, Boston Harbor, sewage discharged near, amount of..... 20

O.

Ohio, chemical precipitation in..... 96
purification plants in..... 95
septic treatment in..... 51
Oldham, England, contact treatment at. 63, 73, 91
sedimentation at..... 91
septic treatment at..... 51, 52, 118
Osdorf, Germany, sewage farm at. *See* Berlin.
Oxygen, amount required for complete oxidation..... 16

P.

Paris, regulation in, concerning discharge of waste..... 9
sewage farms at..... 25
Parry, Kaye, chemical method used by, in Ireland..... 35
Pawtucket, R. I., sludge from filtration process at..... 42
Perkins, W. H., experiments by, on purification processes..... 89
Phelps, E. B., work of..... 7
See also Winslow, C.-E. A., and Phelps, E. B.
Phelps, E. B., and Farrell, F. W., on contact process..... 72, 73
Philbrick, E. S., on sewage tank..... 43
Pittsfield, Mass., intermittent filtration at.. 40, 42
Plainfield, ——, septic treatment at..... 51
Pratt, R. W., jr., on forced aeration..... 76
on Ohio purification plants..... 51, 95
Precipitation. *See* Chemical precipitation.
Prescott, S. C., work of..... 9
Providence, R. I., chemical precipitation at. 34, 96

R.

Rafter, G. W., and Baker, M. N., on analyses of water from Illinois and Michigan Canal..... 17
on manurial value of sewage..... 28

Page.

Reid, G., experiments by, on trickling filtration 82
See also Wilcox, J. E., and Reid, G.
Ribble district, England, contact treatment in 74
Richmond, England, chemical precipitation at 118
Rideal, S., on bacterial action 73
on contact process 56
on Hermite process of sewage treatment 35
on necessity of anaerobic putrefaction .. 52
on self-purification of streams 20
on septic process 43-44, 52
on sewage farming 25
on sewage nitrification 38
on trickling filtration 78, 83
Rivers, self-purification of 17-20, 21-23
Rivers pollution commission, Great Britain. *See* Great Britain.
Robinson, H., on chemical precipitation 32
on sedimentation 116
Rochdale, England, trickling filtration at ... 83
Roechling, H. A., on sewage farming 25
Rogers, Anne F., work of 9
Royal sewage commission Great Britain. *See* Great Britain.
Rugby, England, sewage farm at 27
Russell, H. L. *See* Jordan, E. O., Russell, H. L., and Zeit, F. R.

S.

Salford, England, chemical precipitation at . 32
experiments with anaerobic filters at ... 45
septic treatment at 118
trickling filtration at 77, 78, 79-80, 81, 83
Salt Lake City, Utah, sewage farm at 96
Saltley, England, sedimentation at 116
Sand filtration. *See* Filtration, intermittent.
Sanitary research laboratory. *See* Sewage experiment station.
Saratoga, N. Y., septic treatment at 50, 53, 95
Saxonville, Mass., pollution of Sudbury River at 18
Schloesing, T., and Muntz, A., on sewage purification by bacteria 35
Schultz-Schultzenstein, —, on sewage purification by bacteria 38
Schury, —, experiments by, on purification processes 94
on contact process 74
Schweder, —, experiments by, on purification processes 93
Scott-Moncrieff, W. D., construction of cultivation tank by 43, 45
on trickling filtration 78, 83
Scott-Moncrieff trickling filter, construction of 78, 79, 80
Screening, treatment of sewage by 27, 40, 56, 87, 114, 115, 148
Scudder, —, incubator test devised by 109-110
Sea water, effect of, on sewage, 38, 110, 112-113, 121

Page.

Sedgwick, W. T., introduction by 5-9
investigations in charge of 6, 7
work of, on sewage-purification investigations 37
Sedimentation, treatment of sewage by 27, 29-35, 40, 56, 74, 87, 89, 90, 91, 92, 95, 96, 114, 115, 116-117, 118, 119, 148, 149
Self-purification of streams 17-20, 21-23
effect on, of summer conditions 22
Septic process, comparison of, with chemical precipitation 52
Septic tank, action in, diagram showing 46
advantages of 52-53
closed and open, comparison of results from 44-45, 119-126, 148
development of, at Exeter, England 43
effluents from, analyses of. *See* Analyses.
gas production in, diagram showing 44
rates of treatment in 47, 53
removal of solids by 52
treatment of sewage in 40, 42-53, 56, 58, 74, 88, 89, 90, 91, 92, 93, 94, 95, 96, 117, 118, 119-126, 127, 128, 129, 130, 132, 145, 148, 149
Sewage, amount of, flowing past experiment station 98
composition of 13-16, 112
See also Analyses.
disposal of, by broad irrigation. *See* Sewage farming.
by dilution. *See* Dilution.
nitrogen in, and in sand-filter effluents, diagram showing 130
nuisance created by, in American rivers 21, 22-23
in Thames River, England 21, 30
purification of, by contact process. *See* Contact beds.
by sand filtration. *See* Filtration, intermittent.
by trickling process. *See* Filtration, trickling.
strength of, definition of 107
total nitrogen in, determination of 108
treatment of, by anaerobic putrefaction. *See* Septic tank.
by chemical precipitation. *See* Chemical precipitation.
by septic process. *See* Septic tank.
Sewage-disposal problem, history of 9-96
nature of 9-13
Sewage experiment station, description of, 97-105
experiments at, plan of 105-107
filter house, description of 99-105
plans of, figures showing 101, 102, 104
foundation of 6-7
grit chamber, description of 99
detail of, figure showing 100
operation of 115, 116
location of 97-98
papers published by 7-8
plans of, figures showing .. 98, 100, 101, 102, 104

Page.

Sewage farming, economic advantages of... 28-29
practice of..... 24-29, 74, 90, 91, 92, 93, 94, 96
rates of treatment in..... 25, 26, 27
Sewage of towns commission, Great Britain. *See* Great Britain.
Sewerage systems, number of persons connected with..... 23
Sheffield, England, contact treatment at... 67
septic treatment at..... 50, 118
treatment in coarse filters at..... 118
Shellfish, effect on, of sewage disposal in tide water..... 21
Sludge, character and treatment of, from intermittent-filtration process.. 42
character and treatment of, from precipitation process..... 32
from septic tanks..... 44, 47, 48, 50-51
Smith, E. G., work of..... 9
Smith, J., on character of septic effluent ... 121
Solids, suspended, removal of, in septic tank..... 49-51
Somerset House, England, dissolved gases in Thames River at..... 19
Sorby, H. C., on rôle of bacteria in sewage purification..... 54
South Norwood, England, sewage farm at.. 27
Southbridge, Mass., intermittent filtration at..... 40, 42
Spalding, G. R., acknowledgments to..... 149
work of..... 9
Spencer, Mass., intermittent filtration at... 40, 42
Starch, oxidation of..... 16
Stearic acid. *See* Fat.
Stearns, F. P., on self-purification of streams 21
Steurnagel, ——, on sedimentation..... 116, 117
on septic process..... 46
Stockbridge, Mass., intermittent filtration at..... 40, 42
Stoddart, F. W., on septic process..... 125
on trickling filtration..... 82
trickling filters constructed by..... 77
Stoddart trickling filter, construction of.... 77, 79
Straining, treatment of sewage by.... 117, 118-119
Streams. *See* Rivers.
Stuttgart, Germany, contact treatment at. 74
experiments at, on purification processes..... 94
Sudbury River, Mass., self-purification of... 17, 18
Sulphite-pulp mills, waste from, effect of, on sewage purification..... 12
Suspended solids. *See* Solids, suspended.
Sutton, England, contact treatment at..... 56-57, 63, 67, 68, 70, 88, 118
sedimentation at..... 116
septic treatment at..... 51, 88-89

T.

Talbot, C. N., construction of sewage tanks by..... 43
Tank, septic. *See* Septic tank.
Technology, Massachusetts Institute of, gift to, for experiments on sewage purification, etc..... 6, 8
Investigations at, on effects of sewage disposal in Boston Harbor..... 20
See also Sewage experiment station.

Page.

Teddington, England, dissolved oxygen in Thames River, at..... 19
Tempelhof, Germany, contact treatment at. 94
Thames River, England, nuisance in, caused by overload of sewage..... 21
self-purification of..... 18, 19
See also Barking; Crossness; London.
Thudichum, G., on contact process..... 57
Thumm, K., experiments by, on contact process..... 58
on contact process..... 59, 66
on German sewage-disposal practice.... 94
See also Bredtschneider, A., and Thumm, K.; Dunbar, ——, and Thumm, K.
Tipton, England, trickling filtration at..... 82
Towchester, England, sewage tank at..... 43
Trickling process. *See* Filtration, trickling.
Trinidad, Colo., sewage farm at..... 96
Triple-contract treatment, results of..... 71, 91
Typhoid bacilli, life of, in water..... 11

U.

Urbana, Ill., septic treatment at..... 43, 95

W.

Walker, A. W. *See* McManus, J. H., and Walker, A. W.
Waring, G. E., jr., experiments by, on forced aeration..... 75-76
Warington, ——, on sewage nitrification. 38
Wastes, industrial, pollution by..... 12, 18, 27, 31, 33, 41, 50, 89, 93, 94
Water supply, contamination of, by sewage 21
Watson, J. D., on bacterial treatment of sewage..... 36
on chemical precipitation..... 31, 90
on contact process..... 67
on sedimentation..... 90
on septic process..... 52, 90
on sewage farming..... 25-26, 90
on trickling filtration..... 79, 83
Wauwatosa, Wis., intermittent filtration at 132
septic treatment at..... 46, 51, 53, 95
Webster process of sewage treatment, description of..... 35
Wellington, England, contact treatment at. 64
West Bromwich, England, contact treatment at..... 63-64
Westboro, Mass., intermittent filtration at. 40, 42
Westend, Germany. *See* Charlottenburg.
Whittaker, ——, on trickling filtration... 81, 82
Whittaker-Bryant trickling filter, construction of..... 79
Wilcox, J. E., and Reid, G., on trickling filtration..... 82
Wilkinson, J. B., experiments by, on purification processes..... 91
Willcomb, G. E., work of..... 9
Winslow, C.-E. A., on purification plants of Middle West..... 95
on septic process..... 46, 51
on trickling filtration..... 86
work of..... 7
See also Woodman, A. G., Winslow, C.-E. A., and Hansen, P.

Page

Winslow, C.-E. A., and Phelps, E. B., on European sewages 15-16
Wisconsin, septic treatment in 95
Wolverhampton, England, trickling filtration at 83, 84
Woodman, A. G., Winslow, C.-E. A., and Hansen, P., on self-purification of Sudbury River, Mass 18
Woody fiber. *See* Cellulose.
Woolwich, England, dissolved gases in Thames River at 19
Worcester, Mass., chemical precipitation at 32-33, 34
intermittent filtration at 40, 41, 42
septic treatment at 50
sewage of, effect of acid-iron waste on. 12, 41, 50
Worcester, Mass., sewage of, strength of .. 111
Wrexham, England, sewage farming at 25-26

Y.

Yeovil, England, contact treatment at 73
septic treatment at 51
York, England, chemical precipitation at ... 91
contact treatment at 63
septic treatment at 91
trickling filtration at 81, 83, 84, 88, 91

Z.

Zahn, C., experiments by, on contact process 58, 94
Zeit, F. R. *See* Jordan, E. O., Russell, H. L., and Zeit, F. R.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 185.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress, for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at practically cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities thruout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the fifteenth in Series L, the complete list of which follows (WS= Water-Supply Paper):

SERIES L, QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls. (Out of stock.)

WS 22. Sewage irrigation, Pt. II, by G. W. Rafter. 1899. 100 pp., 7 pls. (Out of stock.)

WS 72. Sewage pollution near New York City, by M. O. Leighton. 1902. 75 pp., 8 pls.

WS 76. Flow of rivers near New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.

WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 132 pp. 15 pls.

WS 103. Review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp.

WS 108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.

WS 113. Strawboard and oil wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.

WS 121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 159 pp., 13 pls.

WS 144. The normal distribution of chlorine in the natural waters of New York and New England, by D. D. Jackson. 1905. 31 pp., 5 pls.

WS 151. Field assay of water, by M. O. Leighton. 1905. 77 pp., 4 pls.

WS 152. A review of the laws forbidding pollution of inland waters in the United States, second edition, by E. B. Goodell. 1905. 149 pp.

WS 161. Quality of water in upper Ohio River basin and at Erie, Pa., by S. J. Lewis. 1906. 114 pp., 6 pls.

WS 179. Prevention of stream pollution by distillery refuse, based on investigations at Lynchburg, Ohio, by Herman Stabler. 1906. 34 pp., 1 pl.

WS 185. Investigation on the purification of Boston sewage, by C.-E. A. Winslow and E. B. Phelps. 1906. 163 pp.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

NOVEMBER, 1906.